Journal

of

The Franklin Institute

NOVEMBER, 1953

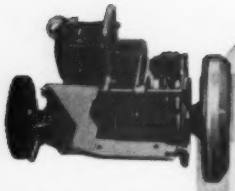
1826

1953

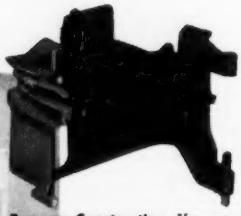
Published Monthly at Lancaster, Pa., by

THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA

PHILADELPHIA, PA.

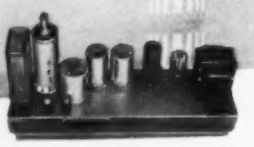


Reserve Power. Speedomax can operate at any speed from a whiz to a saunter, because balancing motors are two to four times more powerful than in any other present-day electronic controllers. A heavy load of control and signal cams makes no difference. The long Speedomax shaft and big case can accommodate a worlds-record assortment of such accessories.



Reserve Construction. You may think all instruments are "delicate", until you look at a Speedomax. Then you'll see forgings and castings instead of stampings; cut, heat-treated gears instead of cast; ball bearings instead of sleeves. You'll see aluminum used, to save weight; parts made extra-strong to prevent deflections. You'll see, in detail after detail, how rigid construction gives rigid dependability.

Locked-in Synchronism. Synchronization of control, recording and signalling actions is permanently fixed because their actuating cams are locked on a common shaft. Obvious? Yes, but in this field a Speedomax exclusive.



Reserve Sensitivity. A change of one tenth of one percent of the range is picked up by Speedomax. The instrument therefore, never strains to keep its readings precise, even when the range is short.

Reserve "Cleanness" Speedomax has superb filtering and (when needed) shielding, but neither can guarantee that the electronic recorder's circuit will be unaffected by electronic "junk" from nearby motors, or other equipment. So, we provide a unique "clean" circuit design—and thereby cancel the junk that would otherwise slow down the balancing motor. Net effect is snappy and accurate recording action.

SPEEDOMAX® "Reserves"

ARE ALWAYS ON THE JOB!

● You get extra-fine performance, day-in and day-out, from Speedomax Recorders or Controllers because they are full of reserves to meet the "unusual" conditions which can and do come up so frequently. And these reserves of course give low maintenance as well as fine performance.

Why not inspect these evidences of quality the next time you need an automatic electronic potentiometer or bridge. See Catalog ND46(1) and (for circuitry) Tech. Pub. ND46(1). Address our nearest branch office, or 4992 Stenton Ave., Philadelphia 44, Pa.

LEEDS & NORTHRUP
instruments *automatic controls* • *furnaces*

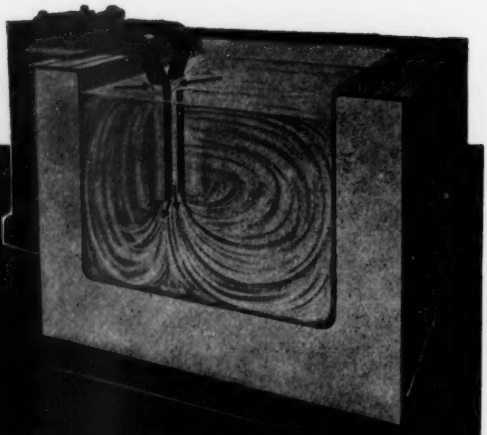
Ad. ND46(14)

INDEX TO ADVERTISERS

	PAGE
Ajax Electric Co.	ii
Almo Radio Co.	xiv
American Chemical Paint Co.	iv
Atlas Photo Engraving Co.	xv
Beemer Engineering Co.	iii
Bell Telephone Laboratories	vi
Biddle Co., James G.	xiii
Bolger-Parker Co.	xv
Buten, M., & Sons	xv
Coleman, W. B., & Co.	xi
Damon & Foster	xi
Davidson, P. L.	xi
Dodge Steel Co.	ix
Eggly-Furlow Engineers	xi
Fehr & Johnson, Inc.	xv
Fidelity-Philadelphia Trust Co.	x
FRANKLIN INSTITUTE, Awards	xvi
FRANKLIN INSTITUTE, Laboratories	Fourth cover page
FRANKLIN INSTITUTE, Membership	Third cover page
Harris-Dechant Associates	xi
Herbach & Rademan	xv
Hess & Barker	ix
Kearney Lumber Co.	xv
Lancaster Press, Inc.	xii
Leeds & Northrup Co.	Second cover page
Leopold, Charles S.	xi
Levy, Max & Co.	xiv
Philco	viii
Radio Electric Service Co. of Penna., Inc.	xiv
Renninger & Graves	ix
Shanahan & Co.	xv
Steinberg, Albert, and Company	ix
Thomas, Arthur H., Co.	xiv
Yarnall-Waring Co.	xii

Entered as second-class matter March 14, 1928, at the post office at Lancaster, Pa., under act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in paragraph (d-2), section 34.40, P. L. & R. of 1948, authorized on July 3, 1919.

OVER 4,000
AJAX INSTALLATIONS
THROUGHOUT INDUSTRY
... more than all other electric salt baths combined!



The Most Efficient Heat Treating Principle

...for CARBURIZING • CYANIDE HARDENING • NEUTRAL HARDENING • ANNEALING OR HARDENING STAINLESS STEEL • BRAZING • HARDENING HIGHSPEED STEEL • AUSTEMPERING • MARTEMPERING • PROCESS ANNEALING • CYCLIC ANNEALING • DRAWING (Tempering) • SOLUTION HEAT TREATMENT • DESCALING • DESANDING • CLEANING

In the Ajax Electric Salt Bath, utilizing immersed electrodes, all heat is generated within the bath itself—the liquid salt acting as a "resistor". Electrodynamic forces produce vigorous circulation throughout the bath, in the downward motion indicated. This is precisely opposite to the upward thermal flow—dependent on a temperature difference in a bath—which exists in other salt bath furnaces. Only Ajax offers electrodynamic circulation!

POSITIVE PROOF..... before you buy!

Before buying heat treating equipment, see exactly what results you will get ... and at what cost! The Ajax Metallurgical Service Laboratory will gladly demonstrate—on your actual products—at no obligation to you.

AJAX ELECTRIC COMPANY, INC.

Frankford & Delaware Aves., Philadelphia 23, Pa.

World's largest manufacturer of electric heat treating furnaces exclusively

Associate companies: Ajax Electric Furnace Corp., Ajax Electrothermic Corp. Ajax Engineering Corp.

AJAX ELECTRIC SALT BATH FURNACES

SAFEGUARD your PRODUCTION with OILITE
OILITE bearings and powder metal parts in your products will improve their performance.
OILITE bearings used in the maintenance of your production equipment will provide maximum security against those breakdowns that give no warning.
OILITE is a heavy-duty, oil-cushioned, self-lubricating bearing material available in bronze, iron (Super-Oilite), and stainless steel Warehouse stocks include thousands of sizes.
Plain, Flange and Thrust Bearings
Cored and Solid Bars
Plates and Strips
OILITE
A CHRYSLER PRODUCT
BEEMER ENGINEERING COMPANY
Main Office & Warehouse: 401 N. Broad St., Philadelphia 8, Pa., Tel. WAlnut 2-6997
BRANCH OFFICES
NEW YORK 17, N.Y. 122 East 42nd Street Murray Hill 6-0171
SYRACUSE 1, N.Y. P.O. Box 1224 Baldwinsville 662
ROCHESTER 10, N.Y. 95 Landing Road, North Culver 3531
BUFFALO 2, N.Y. Prudential Building Mohawk 9222
RICHMOND 19, VA. 216 South Fifth St.

CHEMICALS ACP PROCESSES

PHOSPHATE COATINGS TO MAKE YOUR PRODUCT DURABLE*

PIONEERING RESEARCH AND DEVELOPMENT SINCE 1914

For more than a third of a century, ACP research chemists and ACP technical representatives in the field have pioneered in the science of metal preservation. They have developed surface treating chemicals which either protect metals directly, or create a superior bond for decorative and protective paint finishes, and now, ACP chemicals and processes are being used the world around to reduce costs, speed production and add to the life-span of countless products.

ACP metal protective chemicals include: protective coating chemicals for steel, zinc and aluminum; metal cleaners and rust removers; final rinse controls; pickling acid inhibitors; copper coating chemicals; soldering fluxes; alkali cleaners and addition agents; copper stripping and brightening solutions.

PAINT BONDING

"GRANODINE"® zinc phosphate coatings improve paint adhesion on automobiles, refrigerators, projectiles, rockets, and many other steel and iron fabricated units or components.

"LITHOFORM"® zinc phosphate coatings, make paint stick to galvanized iron and other zinc and cadmium surfaces.

"ALODINE"® protective coatings provide improved paint adhesion and high corrosion-resistance for aircraft and aircraft parts, awnings, wall tile, signs, bazookas, and many other products made of aluminum.

RUST PROOFING

"PERMADINE"® zinc phosphate coatings provide rust and corrosion proofing for nuts, bolts, screws, hardware, tools, guns, cartridge clips, and many other industrial and ordnance items.

PROTECTION FOR FRICTION SURFACES

"THERMOIL GRANODINE"® manganese-iron phosphate coatings provide both rust proofing and wear resistance — anti-galling, safe break-in, friction on rubbing parts.

IMPROVED DRAWING AND COLD FORMING

"GRANODRAW"® zinc phosphate coatings make possible improved drawing, cold forming and extrusion on such steel products as sheets for stamping, bumpers, parts to be formed, prior to plating or painting, cartridge cases, etc.

*Made, Sold, and Serviced By A Pioneer In Protective Coatings For Metals . . .

AMERICAN CHEMICAL PAINT COMPANY

General Offices: Ambler, Penna.

Detroit, Michigan — *Niles, California* — *Windsor, Ontario*

THE FRANKLIN INSTITUTE

OFFICERS

President ..... S. WYMAN ROLPH
Executive Vice-President ..... HENRY B. ALLEN
Vice-Presidents ..... RICHARD W. LLOYD, G. H. CLAMER, JAMES H. ROBINS, MORTON GIBBONS-NEFF
Secretary ..... HENRY B. ALLEN
Treasurer ..... HAMILTON VAUGHAN BAIL
Assistant Secretary ..... HAMILTON VAUGHAN BAIL
Assistant Secretary ..... JOHN FRAZER
Assistant Secretary ..... CECIL M. WATERBURY
Assistant Treasurer ..... CECIL M. WATERBURY

BOARD OF MANAGERS

Term expires in 1954	*Term expires in 1955*	*Term expires in 1956*
EDWARD G. BUDD, JR.	HENRY B. BRYANS	A. FELIX DUPONT, JR.
W. LAURENCE LEPAGE	FRANCIS J. CHESTERMAN	J. G. RICHARD HECKSCHER
HIRAM S. LUKENS	JAMES CREESE	CLARENCE L. JORDAN
JOHN J. MALICK	RUPEN EKSERGIAN	RALPH KELLY
RICHARD T. NALLE	W. H. FULWEILER	LIONEL F. LEVY
CHARLES S. REDDING	WILFRED D. GILLEN	CHARLES PENROSE
JOHN RUSSELL, JR.	MARSHALL S. MORGAN	R. G. RINCLIFFE
WILLIAM M. SCOTT, JR.		PHILIP H. WARD, JR.

The following are, *ex-officio*, members of the Board of Managers:

President
Executive Vice-President
Vice-Presidents
Secretary
Treasurer
Chairman of the Committee on Science and the Arts
Chairman of the Library Committee

GEORGE WHARTON PEPPER, Honorary Member of the Board

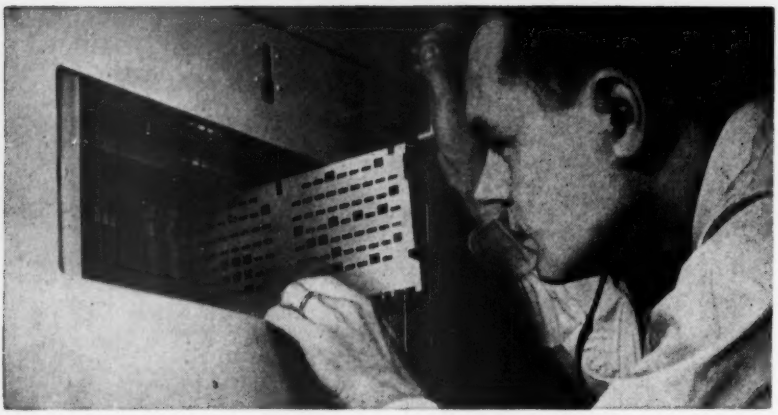
COMMITTEES OF THE BOARD OF MANAGERS

Executive Committee ..... G. H. CLAMER, *Chairman*
Budget Committee ..... JAMES H. ROBINS, *Chairman*
Committee on Board Vacancies ..... CHARLES S. REDDING, *Chairman*
Hostess Committee ..... MRS. FRANCIS H. SCHEETZ, *Chairman*
Committee on Personnel Welfare and Compensation Policy ..... CHARLES S. REDDING, *Chairman*
Vermilye Medal Committee ..... RALPH KELLY, *Chairman*

COMMITTEES OF THE INSTITUTE

Bartol Research Foundation Committee ..... G. H. CLAMER, *Chairman*
Biochemical Research Foundation Committee ..... A. FELIX DUPONT, JR., *Chairman*
Committee on Science and the Arts ..... HIRAM B. ELY, *Chairman*
Endowment Committee ..... MORTON GIBBONS-NEFF, *Chairman*
Finance Committee ..... MARSHALL S. MORGAN, *Chairman*
Library Committee ..... JOSEPH S. HEPBURN, *Chairman*
Meetings Committee ..... NEVIN E. FUNK, *Chairman*
Membership Committee ..... MORTON GIBBONS-NEFF, *Chairman*
Museum and Memorial Committee ..... I. MELVILLE STEIN, *Chairman*
Publications Committee ..... CHARLES B. BAZZONI, *Chairman*
Committee on Research ..... G. H. CLAMER, *Chairman*

The President and the Executive Vice-President are *ex-officio* members of all Committees of the Institute.



Checking perforated metal card in Bell's new "card file." If the first voice-way is in use, a "detour" is swiftly found.

CARDS FOR CONVERSATION

To find out how to route Long Distance calls a dial system needs lots of information – fast. To provide it Bell Laboratories engineers developed a new kind of card file – one that dial systems can read.

Punched holes on metal cards tell how calls should be handled. When a call arrives the appropriate instruction card is displaced so that its pattern of holes is projected by light beams on a bank of Phototransistors, which signal switches to set up the best connection.

The "card file" will have its widest use in speeding Long Distance calls that are now dialed by a telephone operator and may one day be dialed by you personally. It is another example of how Bell Telephone Laboratories helps telephony to grow, as costs are kept down.

New Phototransistor unit. Light entering cylinder is focused by lens on germanium that responds by generating current. Like the Transistor, the Phototransistor was invented in Bell Telephone Laboratories.

BELL TELEPHONE LABORATORIES

IMPROVING TELEPHONE SERVICE FOR AMERICA PROVIDES CAREERS FOR CREATIVE MEN IN SCIENTIFIC AND TECHNICAL FIELDS.

Journal
of
The Franklin Institute

EDITOR, HENRY BUTLER ALLEN, MET.E., D.Sc., Sc.D., D.ENG.
ASSISTANT EDITOR, NANCY S. GLENN, M.A.

Associate Editors:

CHARLES B. BAZZONI, PH.D. — PAUL D. FOOTE, PH.D. — W. F. G. SWANN, D.SC.
ARTHUR L. DAY, SC.D. — C. E. K. MEES, D.SC. — HUGH S. TAYLOR, D.SC.
R. EKSERGIAN, PH.D. — WILLIAM B. MELDRUM, PH.D. — A. F. ZAHM, PH.D.
HENRY C. SHERMAN, SC.D.

Committee on Publications:

CHARLES B. BAZZONI, CHAIRMAN — RICHARD HOWSON — LIONEL F. LEVY
G. H. CLAMER — CLARENCE L. JORDAN — HIRAM S. LUKENS

Vol. 256 **NOVEMBER, 1953** **No. 5**

CONTENTS

Electrical Indicating Instruments Used in Early Edison Central Stations ..... HERBERT B. BROOKS 401

Control of Air Ion Density in Rooms ..... H. H. SKILLING AND JOHN C. BECKETT 423

The Mechanical Design of Muscle-Operated Arm Prostheses ..... ALFRED C. BLASCHKE AND CRAIG L. TAYLOR 435

Notes from the National Bureau of Standards 459

The Franklin Institute

- Minutes of the Stated Meeting 464
- Library 466
- Journal of The Franklin Institute 468
- Membership 468
- Notes from The Franklin Institute Museum 469
- Notes from The Franklin Institute Laboratories for Research and Development 471
- Notes from the Biochemical Research Foundation 473

Book Reviews 476

Current Topics 486

Published monthly by The Franklin Institute of the State of Pennsylvania, Benjamin Franklin Parkway at Twentieth St., Philadelphia 3, Pennsylvania. Printed by Lancaster Press, Inc., Prince and Lemon Sts., Lancaster, Pennsylvania.

Subscription rates: Domestic, $10.00 a year; Foreign, $11.00 a year. Single current issues, $1.00. Reprints, 50 cents per installment. All inquiries regarding subscriptions, change of address, sale of back issues and reprints, should be addressed to the Philadelphia office.

Indexes to the semi-annual volumes of the JOURNAL are published in the June and December numbers.

Copyright, 1953, by The Franklin Institute of the State of Pennsylvania.

QUALITY FIRST

...a Philco Policy

FROM THE MOMENT it is conceived to the moment it is delivered, every Philco product is built to the most rigid standards of performance and dependability. In every step of its design and manufacture, the first consideration is *quality*. No reduction in cost, no economy of production is permitted that makes the slightest compromise with quality or reliability. To the end that, for the price you pay, you may have confidence that the Philco name on any product assures you of the finest quality your money can buy.

PHILCO CORPORATION

TELEVISION • RADIO • REFRIGERATION
ELECTRIC RANGES • HOME FREEZERS • AIR CONDITIONERS
ELECTRONIC PRODUCTS FOR INDUSTRY AND THE ARMED SERVICES

DS

When Buying Steel Castings

Always Remember...

"The Most Effective Alloy in a Steel Casting is Quality"

DODGE STEEL COMPANY

6501 TACONY STREET, PHILADELPHIA 35, PA.

We specialize in supplying *your* needs . . .

From basic parts—such as resistors, tubes, condensers, and transformers—

To newer developments—such as vectors, turret assemblies, transistors, and germanium crystal diodes

FREE PARKING

ALBERT STEINBERG AND COMPANY

2520 N. Broad St., Philadelphia BA 3-9400

Greater Northeast 6324 Sackett St., Philadelphia JE 3-2994

HESS & BARKER

ENGINEERING MACHINISTS

212 S. DARIEN ST.

PHILA., PA.

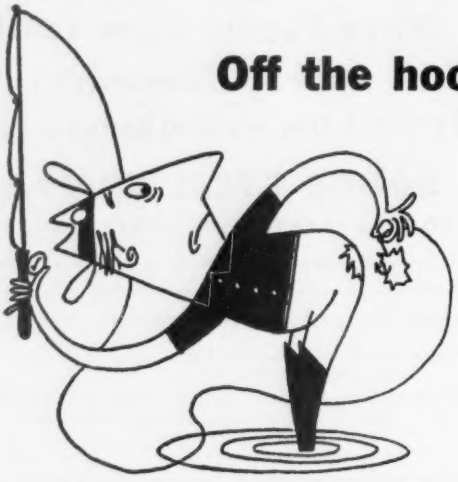
Renninger & Graves

"Every Reproduction Requirement"

Black & White Prints	Roto-Prints	Tracing Papers
Blue Prints	Tracings Reproduced	Drafting Furniture
Photostats	Drawing Materials	Micro-Film

S. W. CORNER 15th and CHERRY STS., PHILADELPHIA, PA.

RITTENHOUSE 6364 RACE 2505



Off the hook

No matter what *individual* you might appoint as the executor of your estate, he might well be out of town . . . on a fishing expedition, for example, or a business trip . . . at the moment your family needs him most.

The way to get "off the hook" is to appoint Fidelity as your executor. Fidelity never takes a vacation, never goes fishing, never falls sick. And Fidelity offers the advantage of *collective judgment* on estate problems that grow ever more complex.

We'll be glad to talk the matter over with you and your attorney.

FIDELITY-PHILADELPHIA TRUST COMPANY

Bankers since 1866

Broad and Walnut Streets
Philadelphia 9

"A billion dollar trust company—a great commercial bank"

Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 256 NOVEMBER, 1953 No. 5

ELECTRICAL INDICATING INSTRUMENTS USED IN EARLY EDISON CENTRAL STATIONS

BY

HERBERT B. BROOKS[1]

1. INITIAL CONDITIONS AT THE PEARL STREET STATION

When operation of this pioneer central station was started in September, 1882, and in fact for some time afterward, there was not a single electrical measuring instrument (ammeter or voltmeter) in the station. The voltage was manually controlled in accordance with the indications of one or another form of signalling device, one of which is shown diagrammatically in Fig. 1, taken from a patent specification. It rang a bell for either high or low voltage. As the diagram indicates, the sound was louder for voltage above normal. The spring which opposed the pull on the armature was adjusted so that the normal voltage held the armature in a middle position with the moving contact clear of both fixed contacts. In a previous similar device high voltage and low voltage were indicated by the lighting of a red lamp or a blue lamp. Apparently such a silent signal was not sufficiently effective. The voltage was brought back to normal by the simultaneous adjustment of the field rheostats of all six "Jumbo" generators. Several of these indicators were used. They were taken to the Edison Machine Works on Goerck Street, New York City, every few days for adjustment in terms of the electromotive force of Daniell standard cells.

The relay-type indicator shown in Fig. 1 was invented by Edison at least a year before the Pearl Street station went into operation. It was an unsatisfactory device, as may be easily realized. Shortly after the opening of the station, Edison applied for a patent on an automatic regulator for dynamo-electric machines, in which a similar relay controlled the amount of resistance in the field circuit of the generator. In this application he proposed to wind the electromagnet of the relay

[1] Physicist, U. S. National Bureau of Standards (retired); Member, Edison Pioneers (1886); Washington, D. C.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

with German-silver wire to avoid errors from self-heating and from variation of ambient temperature.

Although no ammeters were provided in the Pearl Street station, a large astatic moving-magnet galvanometer was set up for the purpose of determining the relative values of the currents in the twenty feeders. This was done by comparing the deflections produced when the terminals of the galvanometer were connected in succession to points at a definite distance apart on each of the feeder conductors. The iron shell of a steam boiler was used as a magnetic shield for the galvanometer.

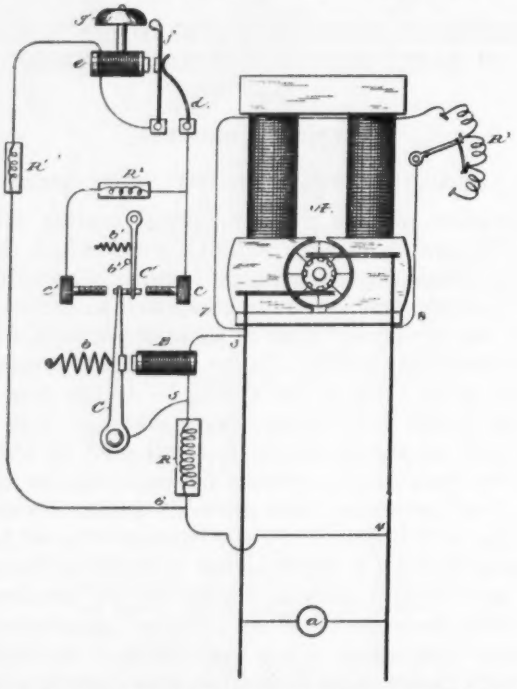


FIG. 1. Relay-type indicator used in early stages of development of the Pearl Street Station.

It was realized at the beginning that the most important quantity to be measured and controlled was the voltage. In the Pearl Street station each generator was driven by its own engine, and an experienced attendant could form a good idea of the relative load on the generator by the performance of its engine. An independent check was given by the shifting of the axis of commutation as the load changed. With the simple shunt-wound generators and copper brushes of that day, every change of load called for a shifting of the rocker arm (which carried the brush holders) to avoid destructive sparking. The angular displacement of this arm from its no-load position was a rough index of the amount of current supplied by the generator.

II. STATION INSTRUMENTS FOR VOLTAGE MEASUREMENT

1. Bradley Bridge Indicator

The sharp dependence of the light output and the life of the lamps upon the voltage at their terminals, and the crudity of the relay-type indicator stimulated the effort to develop better instruments for the measurement of voltage. The first of these was invented by Charles S. Bradley and was known as the Bradley bridge. It is shown diagrammatically in Fig. 2. The four arms of the bridge consisted of two carbon-filament lamps *AA* and two resistors *B* and *C* made of German-silver wire. A galvanometer *D* was connected as shown, and the corners *aa* were connected to the points 3, 4 between which the voltage was to be

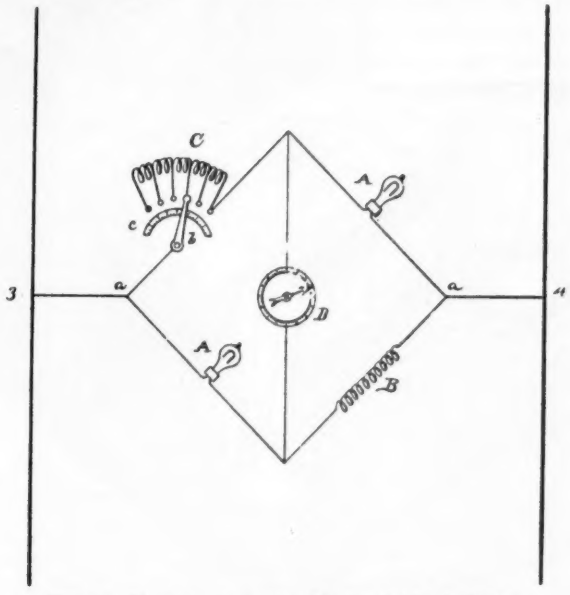


FIG. 2. Diagram of circuits, Bradley bridge indicator.

measured. The resistance of the carbon lamps decreased as the temperature of the filament increased, and for any given value of resistance in the arm *C* the bridge would be balanced for a single definite value of voltage between the points *aa*. The adjustable feature of the arm *C* permitted the use of the bridge to indicate more than one value of voltage with a given pair of lamps. It also made it possible to take care of the unavoidable slow change in the characteristics of the lamps during operation. Figure 3 was made from a drawing of the Bradley bridge indicator, based on pen sketches made from memory by the author and from parts of one of these indicators still in his possession. The indicators were made to be mounted on a shelf located above the generator field rheostats.

The Bradley bridge indicator was used for a time in the Pearl Street station and in at least one other station (Piqua, Ohio). Although it was a great improvement over the relay-type indicator, its indications were affected to an objectionable extent by self heating and by variation of ambient temperature. Furthermore, the use of two lamps required that each of the resistors *B* and *C* had to be large enough to carry the

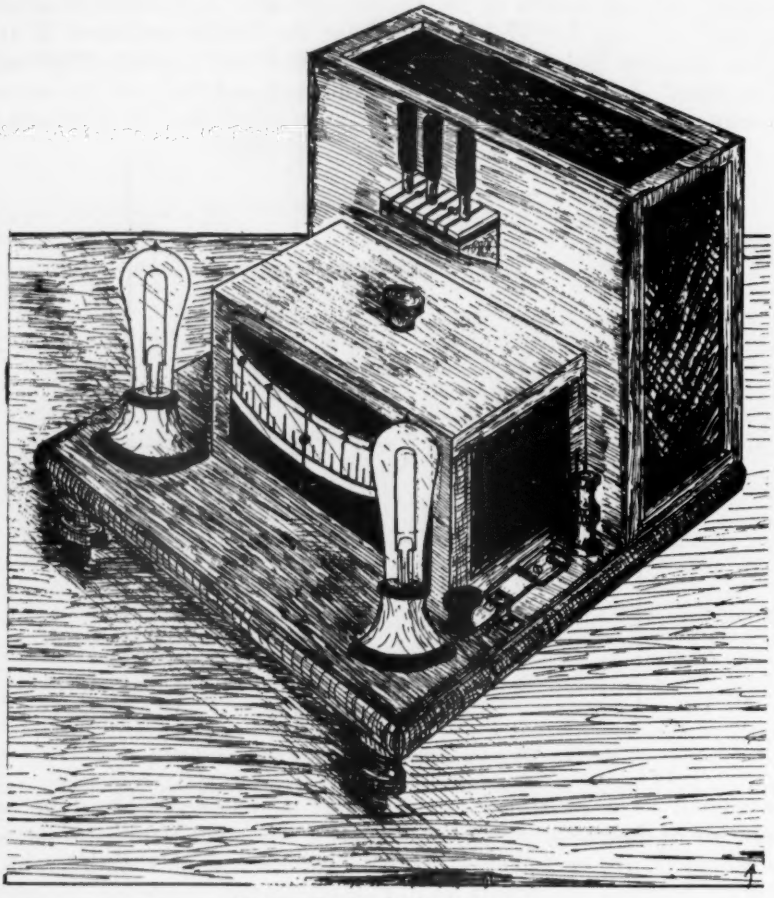


FIG. 3. Bradley bridge indicator.

current of the lamp without undue heating. The power expanded in the two resistors had to be approximately equal to that required by the two lamps. The instrument makers of that day had to use German-silver wire where those of today would use manganin, constantan, or other still more modern alloys. The temperature coefficient of the German silver of that period was large, namely, about one-ninth that of copper. The Bradley bridge was relatively large and expensive, and

these shortcomings and its room-temperature error led to its replacement by the more accurate bridge-type indicators developed by John W. Howell at the works of the Edison Lamp Company at Harrison, New Jersey.

2. *Howell Indicator, Original Form*

The first "electrical indicator" of John W. Howell was essentially a Bradley indicator modified to reduce the power loss in the coils. As shown diagrammatically in Fig. 4, Howell replaced one of Bradley's lamps by a wire resistor *C*. Where Bradley was obliged to make all four bridge arms approximately equal, Howell was free to depart from this condition. He therefore made the resistance *A* much smaller than that of the lamp, with a corresponding reduction in the power loss as compared with Bradley's design. Howell also made the resistances of

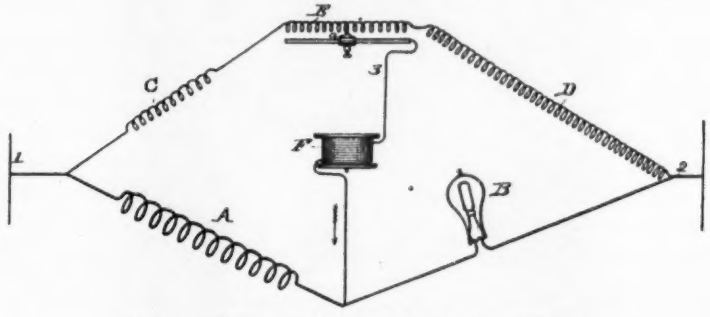


FIG. 4. Diagram of circuits, Howell bridge indicator.

the arms *C* and *D* greater by a factor of about 3 than the resistances of the arms *A* and *B*, respectively. These measures for reducing the power spent in the instrument also tended to reduce the sensitivity of the bridge to changes in the applied voltage, and thus, to secure the same response for say 1 per cent change in voltage, Howell was obliged to use an inherently more sensitive galvanometer. This requirement was met in the Howell indicators as actually constructed.

3. *Temperature-Compensated Indicator*

The next improvement introduced by Howell was intended to reduce or eliminate the change of indication, with a constant applied voltage, caused by internal heating and by change of ambient temperature. The lamp assumed its steady state almost immediately after the application of the voltage, but a relatively long time was required for the temperature of the coils to reach equilibrium. Referring to Fig. 4, the product of the resistances *A* and *D*, when the bridge is balanced, is equal to that of *B* and *C*. As the temperature of the resistors increases, *A*, *C* and *D*

increase in resistance. Thus both factors of the product AD increase but only one of the product BC. The bridge is thus thrown out of balance, and an error in the indication results.

The remedy proposed by Howell was to construct or locate the coil C so that it would increase in resistance proportionately more than A and D, in such a way that the product BC would remain equal to AD as the temperature of the coils increased. Of three methods proposed by Howell, the one preferred by him and adopted in the manufacture of the indicators was to wind all three of the coils A, C and D on the same spool to keep their temperatures equal, and to make coil C partly of German silver and the rest of copper. Figure 5 shows the temperature-compensated Howell indicator as made by the Edison Lamp Company at the Harrison works.

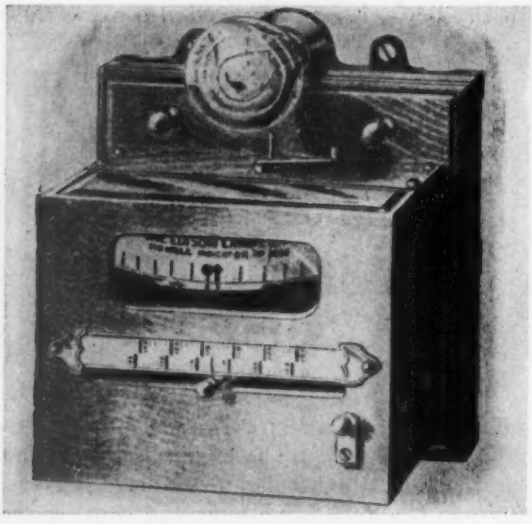


FIG. 5. Howell temperature-compensated indicator.

4. Howell System of Absolute and Comparative Indicators

The efficient operation of an Edison three-wire system of distribution required a close control of the two voltages at the end of each feeder. It was early realized by Howell that the use of a number of indicators, of either of the types just described, would involve a large amount of attention to keep them in correct adjustment. Along with his work on the lamp indicators, he developed a system in which only two such "absolute indicators" were used, connected to "pressure wires" extending back to the station from the end of a chosen feeder (the "standard feeder"). Each of the remaining feeders was controlled with reference to the indications of two "comparative indicators" which were of much simpler construction and did not require frequent checking and ad-

justment. The comparative indicator was essentially a differential moving-magnet galvanometer. Its operation may be explained by reference to Fig. 6, in which for simplicity a two-wire system is shown.

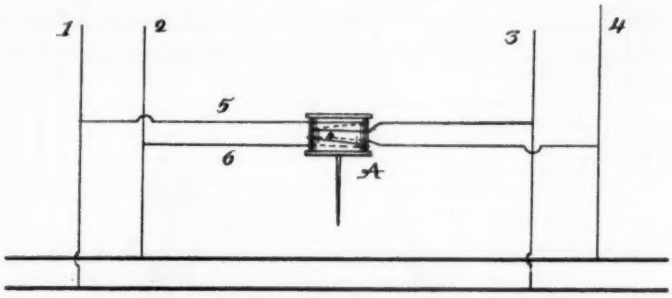


FIG. 6. Howell comparative indicator (diagrammatic), for 2-wire system.

Two branch circuits 1, 2 and 3, 4 from the station busbars are shown and it is desired to indicate the difference in voltage, if any, between selected points on these mains. The moving-magnet galvanometer *A* has two identical windings, one of which is shown connected, by the wire 5, across points of like polarity on the mains 1 and 3; the other winding similarly, by wire 6, between points on the mains 2 and 4. The two galvanometer windings are such as to produce, for equal currents, equal and opposite turning moments on the galvanometer magnet. The pointer will remain at zero as long as the voltage between the tap points on lines 1, 2 is equal to that between the tap points 3, 4. This will be the case, even if the potentials of the tap points on 1 and 3, and between those on 2 and 4, are slightly different, as would usually be the case. If the potential difference between tap points on 1 and 2 exceeds that between points 3 and 4 the galvanometer needle will be deflected in one direction; and conversely. If now we have other means (not shown) by which the voltage between tap points on lines 1, 2 can be indicated and held at the desired value, the very simple indicator *A* will show when the voltage on lines 3, 4 is equal to, higher than, or lower than the controlled voltage between tap points on lines 1, 2. The advantages of this method as applied in central station practice are stated by Howell as follows:

> Central stations, as at present erected on the Edison system, use from 8 to 12 indicators. Each of these is an absolute indicator, and has to be kept in adjustment independently of the others. This requires a great deal of attention and time, and if the instruments are not kept in adjustment they will give wrong indications. The comparative indicators, however, require no adjustment after being once set up; and as it is only necessary to keep one or two absolute indicators in adjustment, it or they will receive more attention and the regulation will be improved. The comparative indicators, also, can be made for much less money than absolute indicators, and where ten or twelve are used this makes a large saving.

The application of comparative indicators to a three-wire system of distribution is shown in Fig. 7, and the comparative indicator itself in Fig. 8.

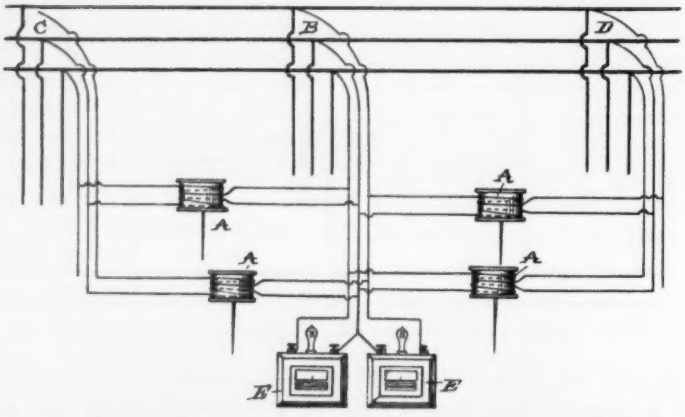


FIG. 7. Howell comparative indicators (diagrammatic), for 3-wire system.

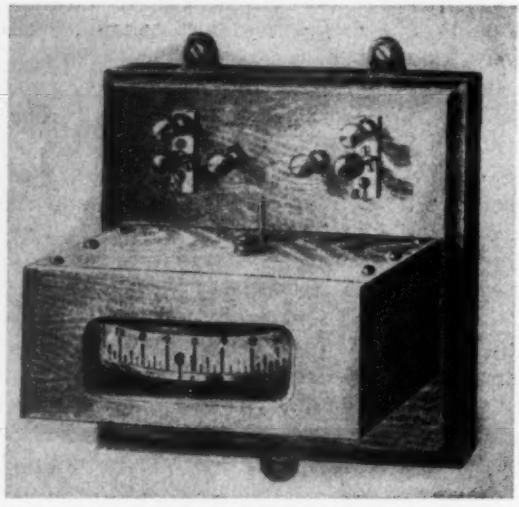


FIG. 8. Howell comparative indicator.

5. Balance Indicator

The use of the comparative system imposed upon the two absolute indicators the heavy responsibility of determining the voltage of the entire distribution system. Although it was contemplated that both of these instruments would be frequently checked, and be readjusted whenever necessary, the need was felt for a special instrument which would

give warning immediately in case any significant change should occur in either of the absolute indicators. The instrument devised by Howell to meet this need was called a "balance indicator" and may be described by reference to Fig. 9, in which the three-wire busbars, mains, and feeder are designated by the letters NCP, $N'C'P'$, and $N^2C^2P^2$, respectively. "Pressure wires" ncp extend from the feeder-end back to a pair of absolute indicators AA' at the station, and separate pressure wires $n^2p^2c^2$ extend back to a balance indicator. This consists of two resistors D and D' connected in series across the outside pressure wires p^2 and n^2, and a galvanometer E connected between the middle pressure wire c^2

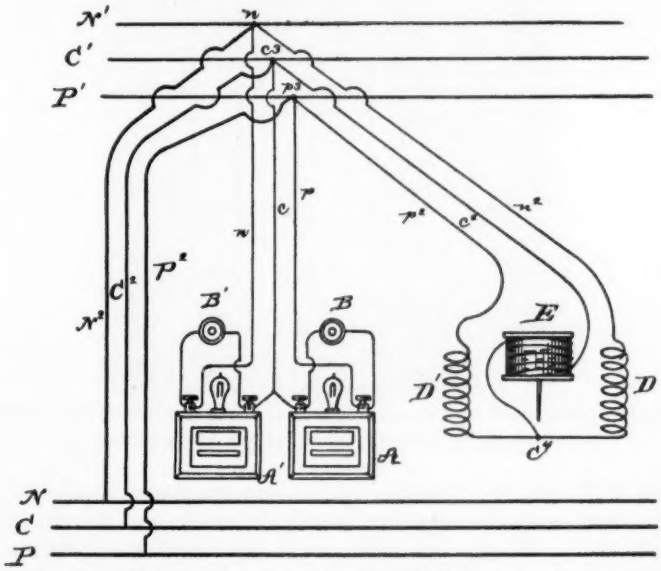


FIG. 9. Diagram of circuits, Howell balance indicator.

and the junction c^4 of D and D'. The galvanometer needle will remain at zero when the voltage between p^2 and c^2 equals the voltage between c^2 and n^2. If the voltages become unequal, that is, if "balance" of the two sides of the system no longer exists, the needle of E will be deflected to one side or the other. If such a deflection occurred while the two absolute indicators showed equality of voltages on the two sides of the system, these indicators came under suspicion and needed investigation. In case one of them had to be taken out of circuit temporarily for any reason, its lamp was removed and screwed into the appropriate socket B or B' in order to maintain a nearly balanced load on the pressure wires ncp, after which the voltage on both sides of the system was controlled by reference to the remaining absolute indicator and the balance indicator.

6. Standardizing Indicator

Still another expedient which was used to keep watch on the two absolute indicators was the so-called standardizing indicator. This was simply a third absolute indicator, normally out of circuit but provided with means for quickly substituting it for either of the two absolute indicators. One way of effecting this substitution is shown in Fig. 10,

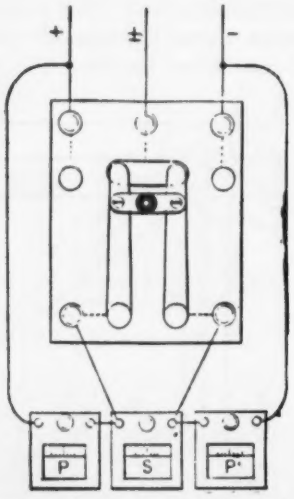


FIG. 10. Diagram of connections of two Howell lamp indicators and a Howell standardizing indicator, connected to a 3-wire system.

in which PP' are the absolute indicators regularly in circuit on the pressure wires from the end of the standard feeder, and S is the standardizing indicator. The switch is shown in the position for normal operation. When thrown to the left it puts S in place of P, and when thrown to the right, in place of P'. This arrangement permitted any one of the three indicators to be removed for repairs or adjustment without interference with the normal control of the voltages on the two sides of the system.

7. Indicator with Work Lamp and Test Lamp

Experience with the absolute indicators showed that although the lamp filaments were operated at a temperature far below the temperature of similar filaments in lamps used for illumination, the resistance of the filaments (for a given current) suffered a gradual change. The indications of the instrument thus became more and more in error as time went on, and it became necessary to provide means for periodically checking and readjusting the indicator. The manner in which this was

accomplished by the inventions of H. Ward Leonard and John W. Howell may be explained with reference to Fig. 11. Two lamps were provided, one marked "work" for regular operation and the other, marked "test," to be used for very short times for checking purposes only. A switch within the indicator, operated manually by means of the lever at the right, cut into the bridge circuit either of these lamps as desired. Instead of the single sliding contact and double scale of the

FIG. 11. Howell indicator with "work" lamp and "test" lamp.

one-lamp indicator (Fig. 5) two sliders were provided. The upper one, with its graduated scale, applied to the "test" lamp; the lower slider, with its scale blank except for a warning legend ("never leave the test lamp burning") applied to the "work" lamp. It was very properly assumed that the test lamp, if subjected to only very brief periods of burning, would retain its characteristics unchanged for a long time, and that consequently the voltage applied to the instrument would be accurately indicated by the position of the upper slider on its graduated scale when the galvanometer deflection was zero. This voltage having been adjusted to the value at which it was desired to operate, the switch was thrown to bring the work lamp into the bridge circuit, and the lower slider was set in the position giving zero deflection.

Like the Bradley bridge indicator, all of the Howell indicators used galvanometers of the fixed-coil moving-magnet form. A small control magnet was provided above the coil to bring the pointer to zero with no current in the coil, regardless of the position in which the indicator was mounted with respect to the magnetic meridian. To guard against

false indications caused by variations in the magnetic field at the instrument, it was necessary to open the galvanometer circuit from time to time and to readjust the needle to zero, if necessary, by turning the control magnet. Eventually, a soft-iron shield was placed around the galvanometer to reduce this source of error.

The Howell indicator, known commercially by the name "Edison pressure indicator," continued to be the standard switchboard instrument for the control of voltage in Edison central stations and isolated plants until the development, by Edward Weston, of the so-called d'Arsonval galvanometer from a laboratory device into a serviceable engineering instrument.

III. BASIS FOR THE CALIBRATION OF VOLTAGE-MEASURING DEVICES

In a broad patent on his system of electrical distribution, applied for by Mr. Edison early in 1880, he proposed to measure the voltage "across the main conductors at the central station, or by return-wire at

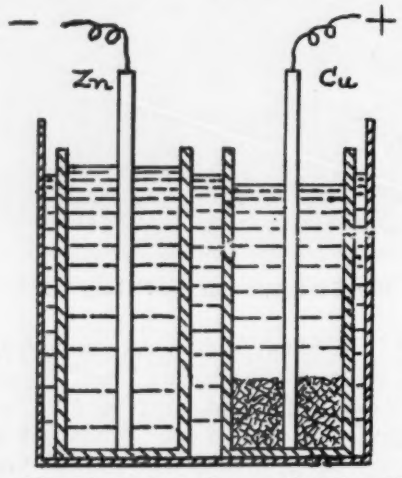


FIG. 12. Cross section of Daniell standard cell as used in Edison Machine Works in 1887.

any point in the circuit" by means of electrodynamometers, galvanometers or electrometers. He adds: "It may be advisable (and I have so done) to place at the central station a series of standard Daniell batteries, connected by a switch-circuit to the galvanometers or electrodynamometers, in order that they may be frequently tested for any inaccuracy occurring from any cause whatsoever." Seven years later, he writes: "As all indicating apparatus is originally standardized by a battery, it follows that a properly constructed battery is the best possible means for securing constant pressures in a station for a long period of time."

The Daniell cell of the early '80's appears to have consisted of an outer glass jar containing a zinc plate in a solution of zinc sulphate, and an inner porous cup containing a copper plate in a solution of sulphate of copper. The electromotive force of the cell was taken as 1.079 volts, "the value assigned by the best authorities." This value was regarded for practical purposes as independent of the temperature of the cell. The cell became useless when the zinc-sulphate solution became contaminated with copper sulphate. To delay this contamination as long as possible, the form of Daniell cell shown in Fig. 12 was used (in 1887) in the testing department of the Edison Machine Works at Schenectady.

IV. PORTABLE INSTRUMENTS FOR VOLTAGE MEASUREMENT

1. Wirt Volt Indicator, Original Form

This instrument, for which an application for patent was filed in 1885, was essentially a potentiometer in which an original form of portable Daniell cell was used. Its plan of circuits is shown in Fig. 13,

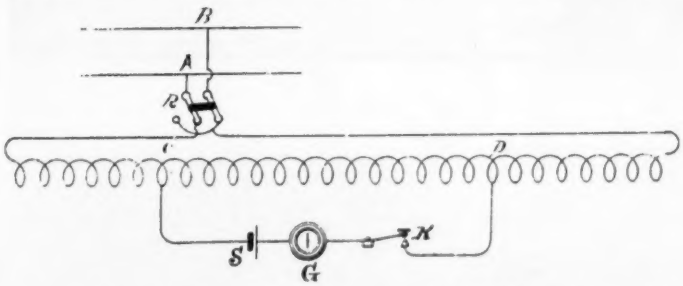


FIG. 13. Diagram of connections, Wirt "volt indicator."

in which S denotes the Daniell cell and A and B are the points between which the voltage is to be measured. Means (not shown) were provided for varying the total resistance AB until the closing of the key produced no deflection of the galvanometer. The complete instrument is shown in Fig. 14, and a cross section of the special portable Daniell cell in Fig. 15. The three bottles were held together by suitable wrappings, and were in communication, through porous diaphragms, by means of openings as shown. The copper plate F is in a copper-sulphate solution and is surrounded by crystals of copper sulphate. The zinc plate G is in a solution of zinc sulphate, as is also the idle zinc plate in the middle bottle. The purpose of the idle zinc plate was "To intercept the copper, which would otherwise be deposited on the active zinc plate and impair its surface." Wirt continues: "It is evident that to increase the internal resistance there may be more than one intermediate compartment, the different compartments opening into each other alternately at top and bottom. Each of said compartments may contain its own idle plate."

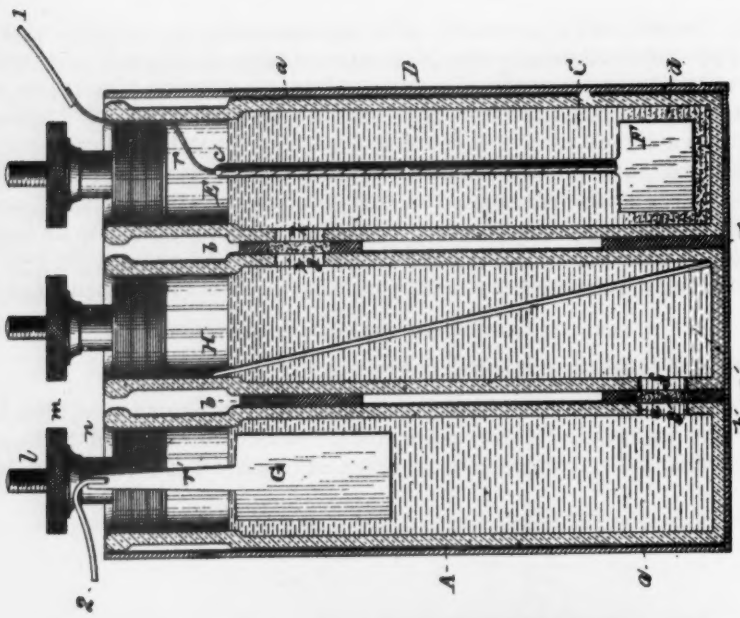


FIG. 15. Wirt "constant cell" in section.

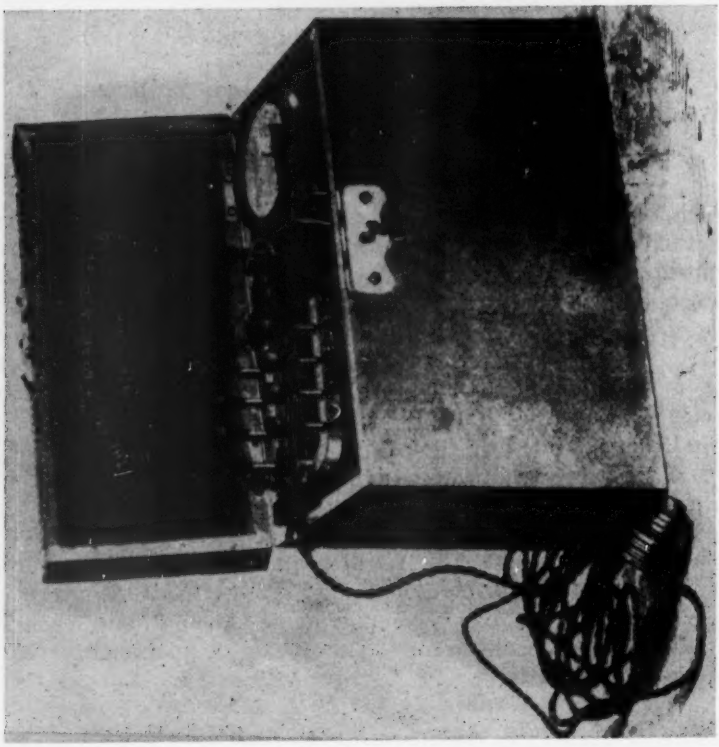


FIG. 14. Wirt "volt indicator."

The Wirt volt indicator was sometimes called a "volt box." This term has been, and still is applied, with an equal lack of logic, to an accessory device for extending the range of a potentiometer.

2. Howell Portable Lamp-Bridge Indicator

Like Wirt, Howell recognized early in his work on measuring instruments that the control of voltage at the feeder ends was not sufficient but that means should also be provided for readily checking the voltage at any lamp on the system. His patent on the temperature-compensated indicator shows as an alternative construction the portable indicator shown in plan view in Fig. 16. This instrument, which was

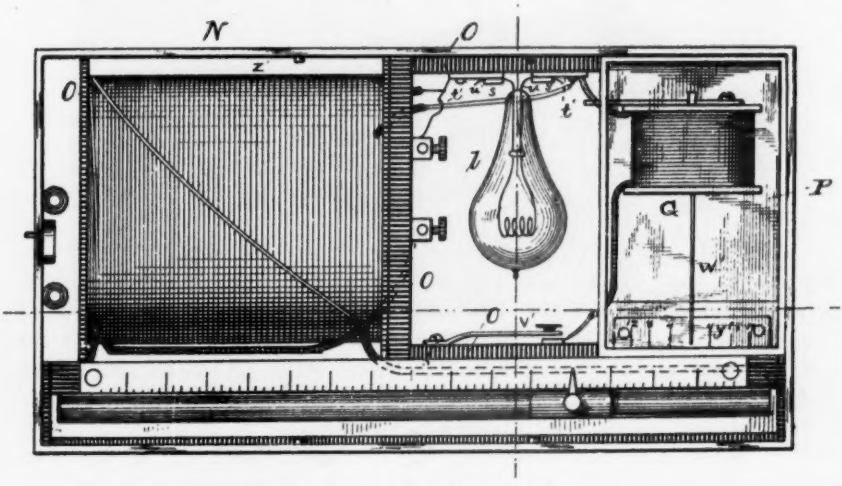


FIG. 16. Howell portable lamp indicator.

called the Howell voltmeter, was small enough (6.5×3.25×1.25 in.) to be carried in a pocket. In its operating principle and plan of circuits it was identical with the Howell temperature-compensated indicator (see Fig. 4). It was more convenient to use than the Wirt indicator when the voltage was not entirely steady, and it avoided the necessity for adding the values of the coils unplugged, as was done in the use of the Wirt indicator.

3. Howell Portable Indicator, Potentiometer Type

The weak spot in the lamp-bridge indicator was the lamp. It was not possible to produce lamps which would retain their original characteristics during a reasonably long period of service; furthermore, it was not possible to duplicate accurately a lamp of given characteristics. The user of a portable lamp-bridge "voltmeter" was obliged to return

it to the factory if the lamp should be broken or should change its characteristics because of extended use, and the replacement of the lamp made it necessary to provide a new scale. To produce a portable indicator which should avoid these drawbacks, Howell devised his portable indicators of the potentiometer type. These indicators were made by the Edison Lamp Company in various forms, all of which were alike in operating principle. The smallest of these indicators was of the same physical dimensions as the Howell portable lamp-bridge indicator above described, and was undoubtedly the first pocket-size potentiometer. The indicator is shown in Fig. 17 and a diagram of its very simple circuits in Fig. 18. The voltage to be measured is applied to the points

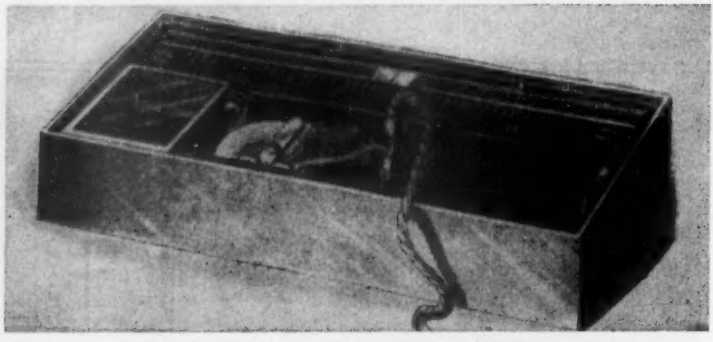


FIG. 17. Howell portable potentiometer indicator.

FIG. 18. Diagram of circuits, Howell portable potentiometer indicator.

P and P' and the slider C is moved until a position is found for which the closing of the key S causes no deflection of the galvanometer. The voltage is then read from a scale alongside the slider.

At first, portable Daniell cells were used. As shown in Fig. 19, this cell was made portable by the use of a relatively thick septum of plaster of paris in the lower part of the U tube. As time went on, the copper-sulphate solution slowly penetrated this diaphragm, coloring it blue. When the blue color reached the zinc-sulphate solution the cell became useless and was replaced by a fresh cell. Later and, very probably as the result of the work of Muirhead in England,[2] a special portable Clark cell was used. The effect of variation of temperature on these Clark cells could not be neglected, and was taken care of in an ingenious way which may be understood by reference to Fig. 20. A thermometer was

[2] ALEX. MUIRHEAD, "New Forms of Standards of E.M.F.," *Electrician*, Vol. 17, pp. 490–491 (1886).

built into the indicator with its bulb near the cells. Its stem was graduated to give directly the correction, in divisions, to the reading on the indicator scale. This correction is zero for an intermediate tem-

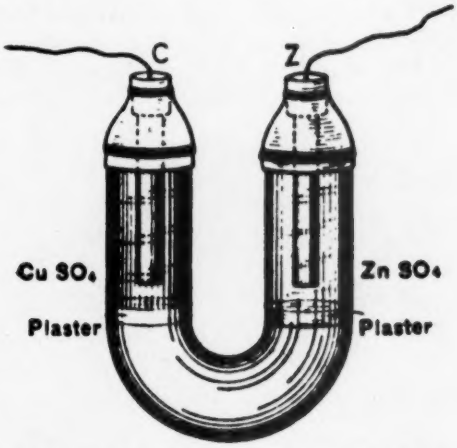


FIG. 19. Howell portable standard cell, Daniell type.

perature and reaches a maximum of ±2 divisions at the ends of the graduation. In the indicator shown in Fig. 20 two Clark cells were provided. They were brought into circuit in various ways by means of plugs placed in the three holes near the galvanometer case. For a voltage within the limits of the scale, a measurement of a steady voltage, made with one of the cells, could be checked by substituting the second cell. If the results did not agree, the cells were open to question. With the cells in good condition, a voltage equal to twice the scale reading could be measured by using the two cells in series.

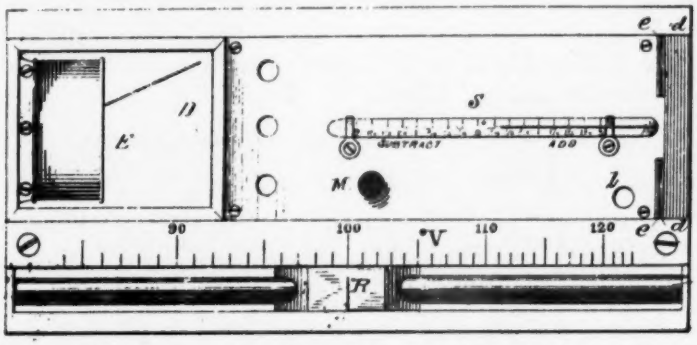


FIG. 20. Device for correcting readings of Howell portable potentiometer indicator for temperature coefficient of Clark standard cell.

3. Wirt "Standard Voltmeter"

This instrument, shown in Fig. 21, differed from the original Wirt volt indicator chiefly in details of construction and manipulation. It was more compact, it read directly from a scale, and there were no loose plugs. The original indicator was limited to measurements in the range 80 to 145 volts. The later form had a scale graduated from 15 volts to 125 volts and a switch to give the range 1.5 to 12.5 volts, both of these

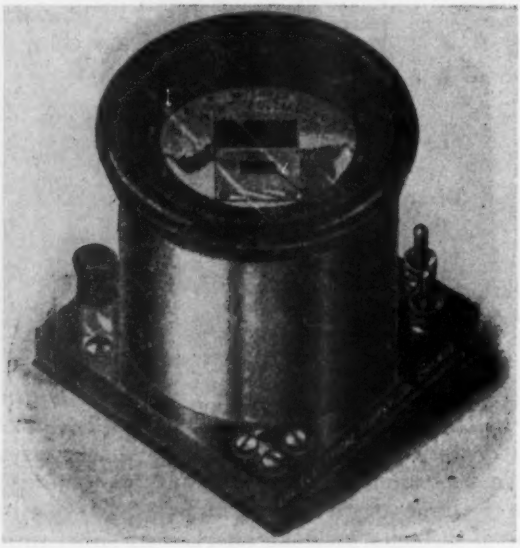


FIG. 21. Wirt "standard voltmeter."

depending on the use of one of the two portable Clark cells within the instrument. As in the Howell indicator just described, the two cells could be compared by measuring the same steady voltage first with one, then with the other cell in use. By connecting the two cells in series, ranges of 3 to 25 and of 30 to 250 volts were obtained. The instrument thus covered the range of 1.5 to 250 volts.

V. STATION INSTRUMENTS FOR MEASUREMENT OF CURRENT

1. The Edison "Ampere Indicator"

This instrument, of which a limited number were used in very early Edison stations,[3] is shown in Fig. 22. The current to be measured

[3] These ammeters were apparently soon superseded. The author was able to locate only one after an exhaustive search over a long period of years. It is in the Ohio State Museum, located on the Ohio State University campus, Columbus, Ohio. The author is indebted to Professor Charles W. Foulk and to Curator John O. Marsh for the photograph from which Fig. 22 was made. The original paper scale had deteriorated so much that a copy of it was put in place temporarily to show the instrument as it was originally.

passes through a flat brass bar, above the middle point of which a soft-iron needle is pivoted to turn about a vertical axis. A permanent magnet holds the needle parallel to the bar when no current is flowing. A current through the bar deflects the needle from this position, and a pointer, carried by the shaft which supports the soft-iron needle, moves over a graduated scale. These ammeters were not satisfactory in service because their indications were seriously affected by currents in adjacent conductors, and they would not hold their calibration because the poles of the "permanent" magnet were so far apart as to make permanency impossible with the kinds of magnet steel then available.

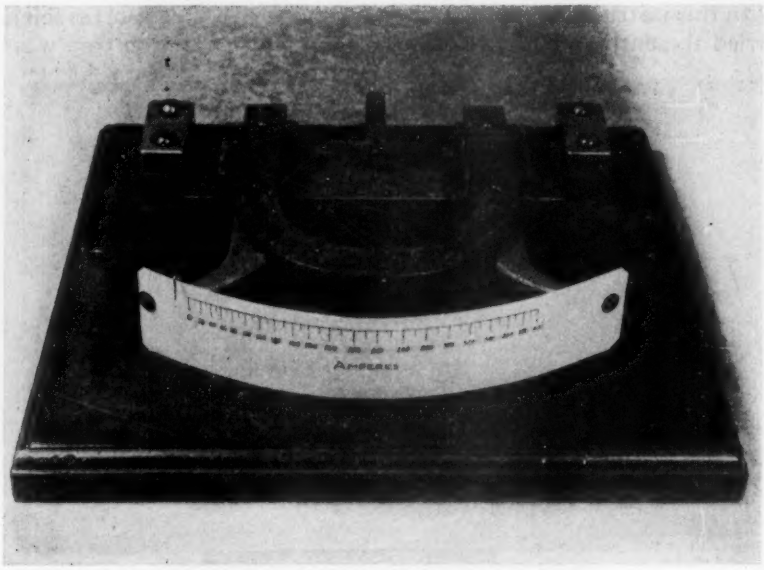


FIG. 22. Edison "ampere indicator."

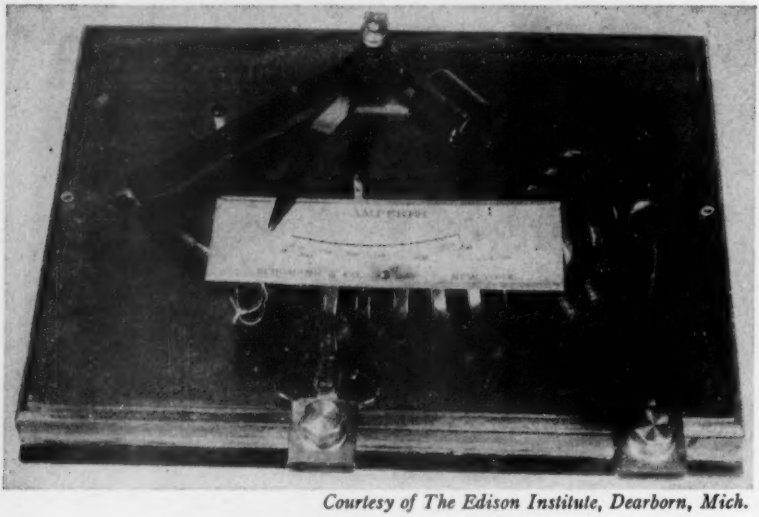
The only description of this ammeter is apparently the one given in what has been called "Edison's Manual of Plant Operation."[4] This manual was a pocket-size book with no title page and no reference to author or publisher. It contained very frank information about the construction and use of the Edison chemical meter, the care of dynamos, procedures in emergencies, meeting gas competition, etc. The description it gives of the "ampere indicator" implies that this instrument was used only in the "omnibus compensating wire," now called the neutral wire. However, in the early Edison station with which the writer was associated, one of these "indicators" was in the neutral busbar and one in one of the outer busbars.

[4] So called in "Forty Years of Edison Service" (book) by T. Commerford Martin (p. 70), published 1922 by New York Edison Company. It is there stated that this manual "Is of the extremest rarity and correspondingly valuable."

Although the "ampere indicator" as shown could be used only with relatively large currents, it was possible to modify it for use with small currents. Mr. Edison, in one of his patents, shows such an instrument to be used, with an added resistance, as a voltmeter. In this case the copper bar is replaced by two coils of wire, one on each side of the soft-iron needle. This arangement was later adopted for the Thomson-Rice[5] direct-current voltmeter, with the soft-iron needle replaced by a soft-iron disk.

2. Solenoid-and-Plunger Ammeter (Pendulum Ammeter)

In this instrument (see Fig. 23) a heavy copper or cast-brass solenoid carried the entire current to be measured. A heavy iron core was ar-



Courtesy of The Edison Institute, Dearborn, Mich.

FIG. 23. Andrews solenoid-and-plunger ampere meter.

ranged to be drawn into the solenoid against the force of gravity acting on a weight. This ammeter was simple, rugged, and dependable. It was not disturbed by stray magnetic fields, and it had no permanent magnet which might weaken and thus introduce errors in the indications. It was invented by one of Edison's right-hand men, W. S. Andrews. His account[6] of the circumstances which led him to develop this instrument is of interest today as revealing the great difficulties encountered by pioneers in electrical engineering, and is therefore given in slightly condensed form, as follows:

[5] "The Thomson-Rice Voltmeter," *Electrical World*, Vol. X, p. 145, September 10, 1887.

[6] W. S. ANDREWS, "Notes on the Testing and Installation of Edison Bipolar Dynamos," *General Electric Review*, Vol. 27, pp. 639–642, September, 1924.

The general appreciation of the Edison lamp resulted in a constantly increasing demand which had to be met by the installation of additional dynamos. Troubles then arose in the heating and destruction of armatures, when two or more dynamos were operated in parallel, owing to the difficulty in dividing the total load evenly between them in the absence of current indicators. After careful consideration of this very serious situation by Mr. Edison, the writer was instructed to devise a cheap and rugged form of ampere meter, one of which could be connected in circuit with each dynamo to show its load. This decision led to the immediate development of the "pendulum ammeter," the readings of which depended solely on the balance between electromagnetism and gravity—no adjusting springs being employed—and the use of these simple instruments immediately checked the armature casualties.

FIG. 24. Andrews ampere meter, later, narrow type.

Variations of the pendulum ammeter were patented by M. Waddel in 1886, W. J. Hammer in 1887, and G. W. Walker in 1890. Waddel's invention consisted in the addition of a rack and pinion by which the relatively limited angular motion of the iron plunger caused a pointer to turn almost a full revolution over a circular scale. Bergmann and Company, New York City, who made chemical meters, sockets, switches, rheostats, cutouts, etc., for the Edison Company, made the original plunger "ampere meters" and also Waddel's variation, the latter in ranges up to several thousand amperes. A plunger-type ammeter,

mounted on a base with leveling screws, was made for portable use for ranges from 1 to 300 amperes.

The original form of pendulum-type ammeter (Fig. 23) had the disadvantage of being too wide for convenient assembly of a number of them side by side. To overcome this, the design was modified (in detail only) as shown in Fig. 24.

The pioneer instruments above described enabled Edison and his associates to get the business of incandescent lighting started, but with the growth of the industry and consequent increase in the magnitudes to be dealt with the inherent limitations of the instruments were keenly felt. The better way, for direct-current measurements, was opened by Edward Weston in 1888 by the introduction of his permanent-magnet moving-coil voltmeter. His shunted ammeter on the same principle made it possible to measure currents so large that none of the earlier methods was feasible. Two years earlier, George Westinghouse had shown how to escape from the drastic limitations inherent in the low-voltage direct-current system by the substitution of alternating current, which can be generated in the most suitable location,[7] at whatever voltage is convenient, stepped up to the particular higher voltage which is economically best for the given distance of transmission, and then stepped down one or more times to lower voltages of magnitudes dictated by the conditions of distribution and utilization.

NOTE: The magnitude and importance of Edison's contribution to our modern life received an unintentional but very impressive tribute at the time of his death. The suggestion was made by writers for the press that during his funeral, precisely at an agreed moment, the main switches of all the power stations in the country should be opened and left so for one minute, then reclosed. Even those familiar with the magnitude of the task of maintaining continuous operation of our vast electric systems could hardly visualize the enormous havoc which such a large-scale indiscretion could cause. The real tribute to Edison lay in the utter impossibility of carrying out the well-meant suggestion.

[7] The direct-current generating plants were located in "central stations" because they *had* to be central, and even then the amount of copper to serve only a limited territory was relatively great. The older term has long ago been superseded by "power plant" or equivalent.

CONTROL OF AIR ION DENSITY IN ROOMS*

BY

H. H. SKILLING [1] AND JOHN C. BECKETT [2]

SYNOPSIS

Studies suggest that ions in the atmosphere affect health and comfort (1, 2, 3, 4).[3] In view of the belief that certain conditions of ionization of the air are beneficial, and others are deleterious, experiments were undertaken to determine how the condition of ionization of air can best be controlled. Attention naturally centers on the condition of ionization of air in living spaces such as residences and offices.

This paper reports on methods of producing and controlling ionization. If charging the air (or the particles in the air) is important, then simple means of ion generation and control will be required in homes and buildings. The physiological tests of ionization have been proceeding since development of this equipment, in laboratories of biochemists and biophysicists, and will be reported elsewhere. To guide the present work it has been tentatively accepted that a moderate excess of negative ionization is beneficial, particularly in relieving respiratory troubles, and that an excess of positive ionization is disadvantageous.

ION PRODUCTION—GENERATION

Ions for improving the condition of air for human consumption must come from a source that is safe, that produces no objectionable or dangerous by-products, and that is preferably simple, sturdy and inexpensive. Two means of generation have been found to be suitable: (1) thermionic generation (emission from hot wires), and (2) ionization by alpha particle emission.

The following means of generation are unsuitable: (1) Ionization by high voltage discharge, because of the dangerous nitrogen oxides and ozone that are produced whenever there is a discharge capable of causing ionization. The danger of ozone is not generally understood, and a discussion is advisable at this point. Ozone results when oxygen molecules of the air are ionized in an electric field (5). The unstable atoms of O and N that result from high voltage discharge also combine to form NO, N_2O_3, N_2O_5, etc. The latter joins water to form nitric acid. Ozone that is inhaled is destructive to tissue because of oxidation. Ozone can be eliminated by heating the air to above 280 C., but this process will also eliminate most of the ions generated. (2) X-rays are unsatisfactory because of the complicated apparatus required and the low efficiency. (3) Photo ionization, including ultra-violet radiation,

* Presented at the Winter General Meeting, American Institute of Electrical Engineers, New York, January, 1953.

[1] Head of the Department of Electrical Engineering, Stanford University, Stanford, Calif.

[2] Chief Engineer, Wesix Electric Heater Co., San Francisco, Calif.

[3] The boldface numbers in parentheses refer to the references appended to this paper.

is not useful because of the complication of apparatus and the relatively small number of ions produced. (4) Radioactive ionization involving beta particles (high speed electrons) or gamma rays (similar to X-rays), is unsafe because of the danger of the radioactive processes.

In the earliest measurements we found that metals at bright red heat, and notably the heating elements of certain electric heaters that operate at such a high temperature as to be visibly bright red or orange-yellow in color, emit positive ions in enormous quantities and only a few negative ions. Positive emission begins at 600 C. (1100 F.) and increases rapidly with temperature. Emission of negative ions from the same heater elements becomes measurable at slightly over 1000 C. (1800 F.). These values vary somewhat with the element wire material, but always adhere to a similar pattern. Negative ion emission increases with temperature more rapidly than does positive ion emission, so that positive and negative ion emissions become equal at about 1200 C. (2200 F.). At higher temperatures negative ion emission would predominate, but the life of ordinary resistance wire in air is extremely short in this high temperature range.

Tests were continued with thermionic sources, including platinum and platinum alloys, ceramic materials and oxides, and these have been reported (6). The objective was to obtain copious production of the desired negative ions and complete absence, if possible, of positive ions. It became evident that some filtering or screening device was required. It was not practicable to produce negative ions without positive ions, so selection of negative ions and suppression of positive ions by some type of electrical filter was indicated.

SEPARATION OF IONS

To increase the amount of ionization of a specified polarity in the air of a room, it is necessary (1) to produce ions, (2) to use some kind of selective process to separate ions of the desired polarity from those of the undesired polarity, and finally (3) to convey the desired ions into the air of the room.

Production of ions is possible in various ways, as noted above, but the method of greatest promise is that of radioactive ionization of air by alpha particles from polonium 210. For radioactive production of ions, polonium offers a safe source of alpha radiation, practically free of beta and gamma rays. The half-life of polonium is short (140 days), but the salt is plentiful and relatively inexpensive. It is probable that radium D can be used to breed polonium and thus prolong the effective life of radiation.

Separation of the positive and negative ions is easily accomplished by an electrostatic field. Undesired ions are drawn, by the force exerted on them by the electrostatic field, toward an electrode of the opposite polarity, where they will be discharged and cease to exist as ions. The

desired ions will, at the same time, be driven by the electrostatic force in the opposite direction. It is then necessary to provide some means to convey these desired ions out of the region in which ion generation takes place, away from the electrostatic field, and into the air of the surrounding room where the ions may be used.

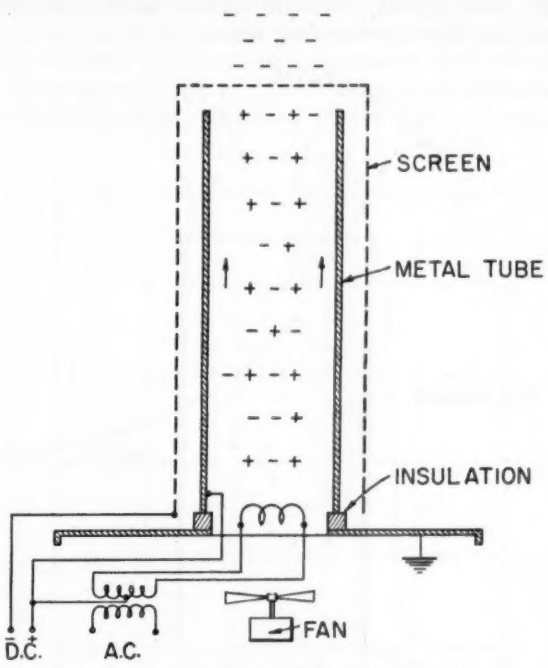


FIG. 1. Ion separation using a charged grid.

Separation of the ions, and propulsion of them into the room, can be done in two ways (7). One way is to use a current of air to convey the desired ions into the room after they have been separated from the undesired ions by an electrostatic field. The other way is to convey the desired ions into the open air by the action of the electrostatic field alone (8). At present, the best results are obtained by a combination of the two methods.

Screen Electrode

An apparatus using the first principle is shown in Fig. 1. Ions emitted from an incandescent filament are carried upward by an air current, either resulting from convection or blown by a fan. The air passes through an enclosing cage of metal screen. The screen is negatively charged by means of a rectifier. As the air, carrying a mixture

of positive and negative ions, approaches and passes through the meshes of the screen, the positive ions are attracted to the screen; on coming into contact with the screen they are de-ionized. The negative ions in the airstream, on the other hand, are repelled by the negative charge on the screen; nevertheless, despite the repulsion, if the current of air is strong enough, the negative ions are carried on through the meshes of the screen and out into surrounding space.

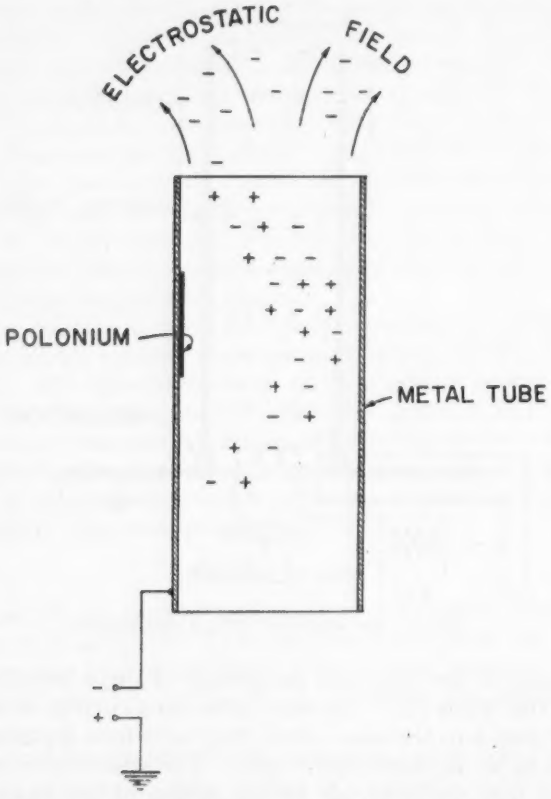


FIG. 2. Ion separation using an external electrostatic field.

Tubular Electrode

An apparatus using the principle of separation by electrostatic means only is shown in Fig. 2. This figure shows an apparatus in which the ionization is produced by polonium. It is characteristic of polonium that the alpha particles (high-speed helium nuclei) emitted from its surface produce ionization of the surrounding air through a range of about 3.6 cm. from the polonium (see Fig. 3) (9). Moreover, such ionization is produced most copiously between 3 and 3.6 cm. from the

surface, for it is in this region that the alpha particles have the velocities that are most effective in producing ionization. It should be emphasized that the dimensions of the apparatus of Fig. 2, and the location of the polonium in particular, are rather critically determined by their relation to the range of alpha radiation from polonium.

In its simplest form, the apparatus is a metal tube about 1.75 in. in diameter, given negative potential relative to ground by a rectifier, and a strip of polonium foil about an inch square centered about 3.5 cm. (about 1.4 in.) below the top of the tube. Alpha radiation from the polonium produces profuse ionization of the air in a region near the

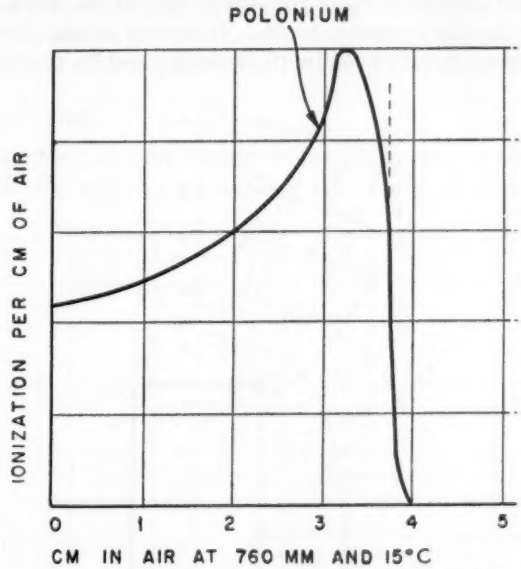


FIG. 3. Ionization by alpha radiation from polonium.

upper end of the tube. (In the diagram, the polonium foil is shown attached to the inner wall of the tube; in another form of the device, the polonium is supported in a central position at the axis of a 3-in. tube, the same distance below the upper end.)

In this apparatus of Fig. 2, the rectifier produces an electrostatic field between the tube and ground. Part of the field is indicated in the diagram, with arrows pointing in the direction in which force will be exerted on *negative* ions. The electrostatic flux lines terminate on the cylinder, and the other end of each line goes to ground or to some grounded object. In actual fact, the distant ends of the flux lines will be on the walls, ceiling, and floor of the surrounding room, and on articles of furniture, or even people occupying the room. (It is customary to consider wood and plaster walls as non-conducting, but under ordinary

conditions of surface dirt and moisture they are quite sufficiently conducting to be at ground potential in electrostatic fields.)

The electrostatic field within the metal tube of Fig. 2 is small but it is not negligible. The field is zero at a cross-section plane (which would be horizontal in the figure) half way between the two open ends of the tube. At a cross-section plane at the upper end of the tube, however, the field is considerable (see Fig. 4). It is quite intense near the sharp corners at the upper edge of the tube and diminishes to a minimum, but by no means to zero, at the axis. Ion separation takes place in this upper region.

When an ion is formed near the upper end of the tube of Fig. 2, it is acted on by the electrostatic force. It moves in the direction of the flux lines at a speed determined by its mobility and by the field strength.

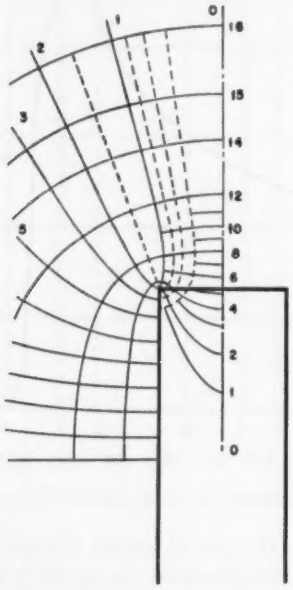


FIG. 4. Electrostatic field of polonium-source negative-ion generator.

A positive ion moves to the negatively charged cylinder, where it loses its positive charge and becomes neutral. It moves slowly because the field is weak within the tube. If an ion were formed just above the upper end of the tube it would be in a region of stronger field and would move more rapidly to the tube and be discharged; however, the polonium is so located that most of the ionization takes place within the tube and near to the surface of the tube.

When a negative ion is formed within the upper half of the tube it moves gradually toward the open upper end, driven by the electrostatic

field. As it approaches the mouth of the tube it moves faster; then beyond the mouth it moves progressively slower as the field strength diminishes in the open space beyond the tube. Within a few inches the field strength has diminished to a small fraction of the strength at the mouth of the tube, and electrostatic forces become so small that the ion is free to drift with whatever natural circulation of air there may be in the room.

Thus, the negative ions that are produced within the ion generator are added to the negative ions in the air of the room. They pass from the influence of the generator and are carried about by the natural circulation of the air. Eventually, they will reach the walls, the ceiling, or the floor of the room, and be discharged, being driven to the walls by their mutual repulsion (by the space-charge field) but until that happens they contribute to the negative ionization of the air in the room.

Effect of Air Current

As long as positive and negative ions are mixed in the same region, as they are in the upper part of the tube of Fig. 2, there will be some

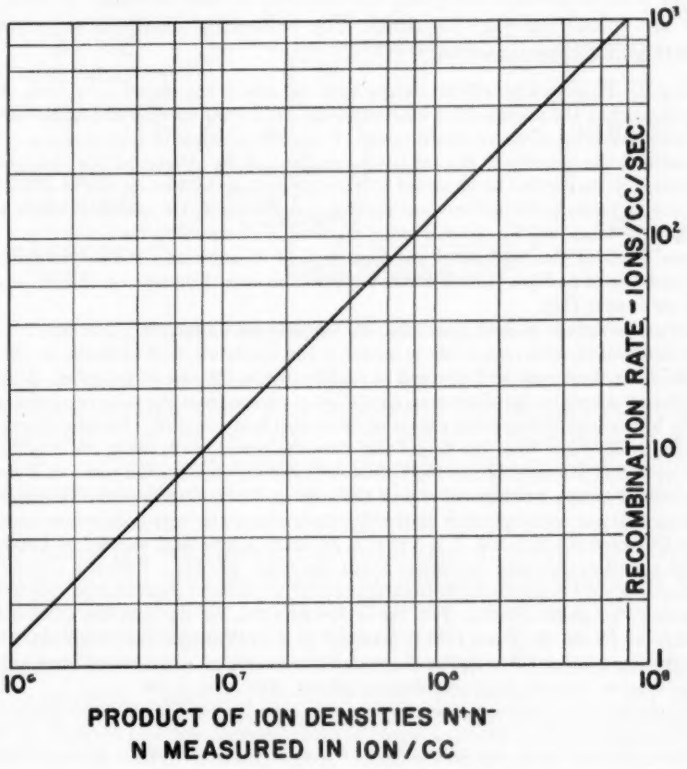


FIG. 5. Recombination rate of ions in air.

recombination of charge and loss of ionization. The ions of opposite sign are mutually attractive, and if they come in contact there is a transfer of charge and both ions become neutral atoms or molecules. Contact is rare because of the relatively great numbers of neutral gas molecules in the space, and recombination is slow. The formation of ions close to the tube surface causes positive ions to be absorbed quickly. Nevertheless, recombination is an appreciable factor (see Fig. 5) (10), and it is helpful in conveying negative ions into the surrounding room to have a current of air passing upward through the tube of Fig. 2.

Such an air current must not be strong enough to carry the positive ions, also, out of the tube; they must be drawn to the tube by the electrostatic field, and be discharged. For maximum production of negative ions, it is necessary to maintain a proper proportion between the air velocity and field strength. It is found that satisfactory operation results if the tube of Fig. 2 is maintained at 50 volts (average) rectified voltage, and the air velocity through the tube is 4 in. (10 cm.) per second. This voltage is conveniently supplied from a conventional 115-volt a-c. domestic service. Obviously, if the voltage is increased, higher air velocities may be used. The following analysis supports this experimental determination.

Analysis.—Positive ions will not escape from the tube if the electrostatic force of attraction is greater than the viscous force exerted on the ion by the moving air; motion of the ion will be in the direction of the resultant force. Using the principle of superposition, it may be considered that the velocity of the ion is the resultant of the velocity of the surrounding air and the velocity that would be imparted by the electrostatic field to the ion in still air. The former may be taken to be uniform and vertical everywhere within and close above the tube of Fig. 2. The latter will be directed along the lines of electrostatic force (see Fig. 4) with a magnitude equal to the product of the electric field strength and the ion mobility. The average mobility of positive "light" ions is known to be approximately 1.6 cm. per second per volt per centimeter (11).

Figure 4 is drawn to help determine the electric field strength. The only value that must be determined with reasonable precision is the maximum field strength on the axis of the tube. This maximum field strength is slightly above the end of the tube. If an ion is carried along the axis by the airstream, its ability to escape from the tube is contingent upon its ability to pass out through this region of maximum field strength. Moreover, ions following any paths of escape from the tube other than the central path along the axis must pass through regions of stronger electric field than does the ion on the axial path, so if an ion on the axis cannot escape, neither can any of the others. Computation of the field strength at an axial point about one centimeter above the upper end of the tube is therefore required.

The field plot of which Fig. 4 is a part is drawn as a graphical solution of Laplace's (or Poisson's) equation assuming free space about the tube (12, 13). Within a few inches the field becomes hardly distinguishable from that about an isolated point charge. In the region of the figure, a graphical solution gives the Stokes function, for the field has axial symmetry. At a radius of 14 cm. the inner field is matched to the radial field that would exist about a point charge, and beyond that radius the variation of potential is computed from well-known formulas based on a radial field extending to infinity (14).

That the field about the ion generator does not, in fact, extend to infinity is not important. Nearby objects at ground potential would actually increase the field strength at the tube above the computed value, but only slightly. A zero-potential surface, however large, at a radial distance of a meter or more (as floor, walls, ceiling) would not increase the field strength more than about 3 per cent.

The field strength at the ion generator depends, of course, on the applied voltage. In its simplest form this is a pulsed voltage resulting from unfiltered half-wave rectification. The measured average potential difference from tube to ground is 50 volts; the average voltage is considered the significant value because the velocity of the ions in air is essentially a linear function of field strength. (The time required for an ion to reach drift equilibrium in air is short compared with 60-cycle frequency.) An air velocity of 4 in. per second is conveniently achieved by using a 2-in., 4-bladed fan on a 600-rpm. conventional electric clock motor.

The combined graphical and analytical solution gives 7 volts per centimeter as the maximum field strength on the axis near the open upper end of the tube. Taking the mobility to be 1.6 cm. per second per volt per centimeter, as given above, a positive ion velocity of 11 cm. per second, or 4.4 in. per second results. Since the measured air velocity is about 4 in. per second, it appears that the electric force, acting in opposition to the viscous force, is everywhere great enough to prevent escape of positive ions.

Thus, the analysis supports the observation that an ion generator with the above dimensions does indeed give effective separation of the two polarities of ions. Some positive ions may be emitted into the surrounding room, but the number of negative ions is greatly predominant.

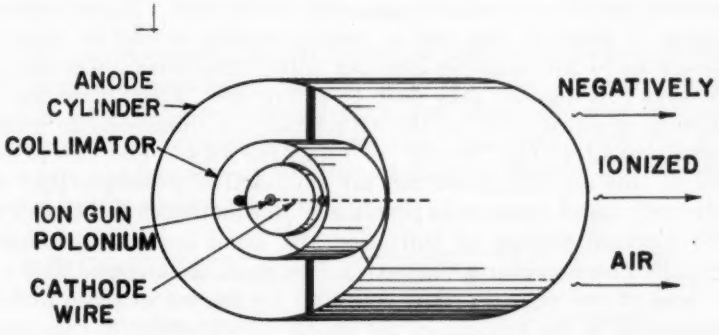


FIG. 6. Ion separation using an internal electrostatic field—radion tube.

Where greater ion dissemination is needed a somewhat different device is used through which a strong electric field is employed, together with relatively high air velocity. This device is illustrated in Fig. 6. Here both a cathode and anode are provided. Negative ions that are formed by the alpha particles in the vicinity of the axis of the tube are attracted toward the outer cylinder but before they can reach this outer cylinder high velocity air that is directed through the tube blows them clear and out into the room. The positive ions follow the strong electrostatic lines of force to the central wire cathode, at which point they are absorbed. The air velocity immediately adjacent to this wire is less than anywhere else in the tube because of the shielding effect of the polonium support. This fact, together with the electrostatic force pulling the positive ions to the wire, is sufficient to eliminate all positive ions that might otherwise be blown out into the room. Typical air velocity used in this device is about 120 in. per second. This unit can be

effectively used in combination with the ventilation for an air-conditioning system; however, it is not suitable for individual room use because of the high air velocities required. The much quieter device illustrated in Fig. 2 is more suitable for use in the individual room. It is important, considering the application of this equipment, that it be particularly free from all noise or sensation of draft; hence, for the present the emphasis has been placed on the unit described herein in detail.

MEASURED IONS

In order to check the effectiveness of ion separation, measuring apparatus was required that would be sufficiently delicate to measure the number of ions that are found in ordinary air in untreated rooms. At the same time this apparatus had to be reasonably rugged and portable, direct reading and capable of producing a continuous record of ionization for periods of at least twenty-four hours. Ordinarily, untreated air as found both indoors and out, on a clear day, contains 400 to 1000 ions of each polarity per cubic centimeter. There is generally an excess of positive ions and a typical reading would be about 600 positive ions to 500 negative ions per cubic centimerer. On cloudy or foggy days this number may drop to 100 or 200 "light" ions per cubic centimeter primarily due to the attachment of these ions to moisture particles, thus forming "heavy" or Langevin ions. The two principal causes of this natural ionization are radioactive materials that occur in extremely small amounts in practically all substances and cosmic rays.

To measure density of ionization the usual apparatus consists of electrically charged plates that attract or repel the charged ions of the air. Ions of one sign are thus collected on the metal plate and from measurement of the amount of the charge it is possible to compute the number of ions collected. By passing a known amount of air through such an instrument, the ion density can be determined (15).

Ion collectors used in this work measure primarily the "light" ions of the air. These are the smallest ions that exist for any considerable length of time in air. There are also larger ions with mobility of the order of 1/100th of the mobility of smaller ions. These larger ions, known as intermediate ions, are becoming increasingly common over cities and certain areas where haze and air pollution are common (16). "Heavy" ions, or Langevin ions, which are microscopic in size, are the largest ions found in air and are too large to be of importance here except as they affect the light ion densities (1, 17).

A simple ion generator designed to generate one polarity of ion, as described in this article, is capable of affecting the space charge in a small room of approximately 1000 cu. ft. The degree of effectiveness is somewhat dependent on the amount of air pollution. The greater the pollution the less the apparent ion density. This characteristic is

found in the laboratory where the ion density measuring equipment is not capable of measuring ions of the light, intermediate *and* heavy sizes.

The *total* ion density is undoubtedly greater since heavy ions will form rapidly and be lost to the walls at a slower rate; nevertheless, the light ion density is less and this is the ion density with which we are most concerned.

A single ion generator, similar to that shown in Fig. 2, will increase the total of light and intermediate negative ions present by approximately 50 per cent under most conditions. At the same time the positive ion density will decrease about 10 per cent. Just what happens under conditions of high humidity is not known, since thus far ion density equipment has not been successfully operated at relative humidities above 60 per cent. Measurements of space charge, however, suggest that the total ion densities at high humidities are even higher than at levels below 60 per cent relative humidity.

CONCLUSION

As one might expect, the ion density is highest in the area closest to the ion generator, and this drops off rapidly to about three feet from the generator. At a distance of three feet or more the ion density throughout the room is fairly uniform except for that area within two feet of the walls where the ion density appears to drop off rapidly as the ions are absorbed by the walls.

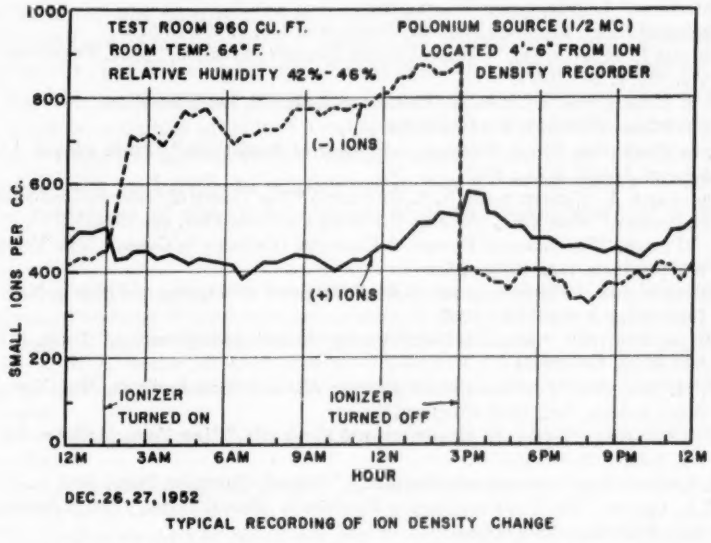


FIG. 7. Change in room ion density using device shown in Fig. 2.

The curves in Fig. 7 illustrate typical recorded values in a small unoccupied room in which ion density with a single ion generator is compared to normal conditions. Generators have been used in animal cages, such as rat cages, and cubicles in which from three to twelve rat cages are installed, and comparable ion densities have been recorded. In a single rat cage of approximately one cubic foot volume, the ion densities may run as high as 20,000 ions per cc., but in cubicles of approximately fifteen cubic feet (this size has been found to be the most successful for biological research), the measured densities are more like that found in a small room and seldom exceed 6000 ions per cc.

As with humans, drafts are an important factor with experimental animals and every precaution is taken to keep air velocities to less than fifty feet per minute. This means that the simple device shown in Fig. 2 has been preferred for the generation of ions in controlled biological experiments. Once the biochemists and biophysicists agree as to the proper application of ionization in air conditioning it will be time to consider stronger ion sources with air velocities up to 200 ft. per minute.

REFERENCES

(1) F. W. HUTCHINSON, "Health Effects of Ions and of Ozone in Comfort Air Conditioning," *Heating and Ventilating*, Vol. 41, March, 1944.

(2) L. R. KOLLER, "Ionization of the Atmosphere and Its Biological Effects," JOUR. FRANKLIN INST., Vol. 214, p. 543 (1932).

(3) C. P. YAGLOU, L. C. BENJAMIN AND A. D. BRANDT, "Physiological Changes During Exposure to Ionized Air," *Heating, Piping, Air Conditioning*, Vol. 5, p. 423 (1933).

(4) FREDERICH DESSAUER, "Ten Years' Research in the Region Bordering on Physics and Medicine," Leipzig, Georg Thieme, 1931.

(5) Technical Notes, Editorial, *Electrical World*, Vol. 138, p. 104 (1952).

(6) THOMAS L. MARTIN, JR., "Climate Control Through Ionization," JOUR. FRANKLIN INST., Vol. 254, p. 267 (1952)

(7) U. S. Patents Nos. 2,576,399, 2,589,613 and 2,594,777, Ion Controllers.

(8) U. S. Patent 2,640,158, Ion Controller.

(9) J. A. CROWTHER, "Ions, Electrons, and Ionizing Radiations," Eighth edition, London, Edward Arnold & Co., 1949.

(10) FREDERICK A. MAXFIELD AND R. R. BENEDICT, "The Theory of Gaseous Conduction and Electronics," New York, McGraw-Hill Book Co., Inc., 1941, pp. 251–252.

(11) L. B. LOEB, "Fundamental Process of Electrical Discharge in Gases," New York, John Wiley & Sons, Inc., 1939, p. 5.

(12) ERNST WEBER, "Electromagnetic Fields," Volume I ("Mapping of Fields"), New York, John Wiley & Sons, Inc., 1950.

(13) HILLEL PORITSKY, "Graphical Field-Plotting Methods in Engineering," *Trans. A.I.E.E.*, Vol. 57, p. 727 (1938)

(14) H. H. SKILLING, "Fundamentals of Electric Waves," Second edition, New York, John Wiley & Sons, Inc., 1948, Chapter IV.

(15) J. A. FLEMING, "Terrestrial Magnetism and Electricity," New York, McGraw-Hill Book Co., Inc., 1939, Chapter V.

(16) J. A. CHALMERS, "Atmospheric Electricity," Oxford, Clarendon Press, 1949, p. 29.

(17) H. L. GREEN, "The Size-Frequency of Particles in Mineral Dusts," *Trans. Faraday Soc.*, Vol. XXXII, p. 1091 (1936).

THE MECHANICAL DESIGN OF MUSCLE-OPERATED ARM PROSTHESES*

BY

ALFRED C. BLASCHKE [1] AND CRAIG L. TAYLOR [1]

ABSTRACT

This paper is concerned with the principles of engineering design associated with the harnessing of human muscle to operate a cineplastic prosthesis. The analysis proceeds on the assumption of a linearized biceps muscle force-length diagram. Four types of mechanical lever systems are proposed to compensate for the loss in muscle force with excursion. Design principles are established for each system and the performance of typical designs are compared.

The harnessing of human muscle to operate mechanical apparatus, such as a cineplastically controlled prosthesis, introduces a novel and significant problem in engineering design. It includes: first, study and measurement of the properties of the muscles concerned; second, an idealization of these properties by introducing an order of approximation suited to the practical problem of utilization; third, definition of the utility requirements; and fourth, design of a mechanical system which matches the idealized properties to the utility requirements. This involves a synthesis of human biology and engineering, which constitutes a particularly apt example of interdisciplinary activity.

The general features of the cineplasty application are presented in Sauerbruch (1),[2] Kessler (2) and Alldredge (3). After surgery and healing, the cinetized muscle toughens from training and use and is fitted with a pin to which is attached a cable operating the artificial prehension device. Figure 1 shows such a biceps muscle tunnel in a below-elbow amputee with and without apparatus in place. This paper is devoted to the principles of design associated with this harnessing of a muscle "motor."

---

* The research reported herein was conducted in the laboratories of the Department of Engineering, University of California, Los Angeles, in partial fulfillment of Contract VAM-23110, sponsored by the Advisory Committee on Artificial Limbs of the National Research Council. L. M. K. Boelter is Chairman of the Department of Engineering and Robert Bromberg is the technical representative of the chairman for the contract research projects of the department.

The authors are indebted to Hyman Jampol for the measurements of muscle forces used in this analysis.

[1] Lecturer in Engineering and Professor of Engineering, respectively, University of California, Los Angeles, Calif.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

MUSCLE PROPERTIES

Of the many aspects of muscular and neuromuscular function pertinent to harnessing of the muscle tunnel, the following have been studied or considered: the force-length diagram, the load-velocity relation, the effect of elbow angle, the relearning of voluntary control, and training effects.

1. The Force-Length Diagram

Although Vanghetti was first to conceive and apply the cineplasty procedure, the first important works begin with the two editions of Sauerbruch. In the second of these (1), the physiologist, Albrecht

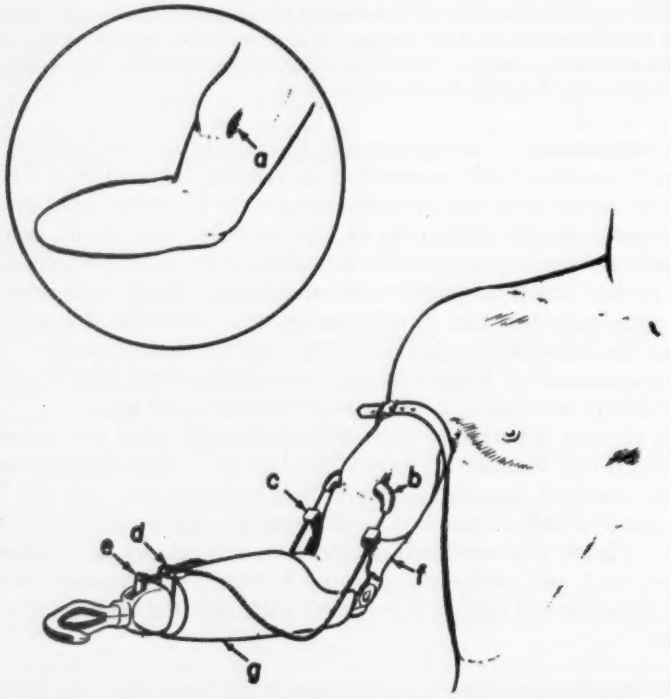


FIG. 1. Below-elbow amputee with biceps cineplastic muscle tunnel.

a, muscle tunnel; *b*, muscle pin; *c*, *d*, transmission (Bowden) cable; *e*, hook lever; *f*, arm frame; *g*, plastic socket over the stump. Muscle tension is transmitted through the twin Bowden cables, running from cable retainers *c* to *d*, which make the cable displacements independent of elbow position.

Bethe, was author of a section on the "physiological point of view concerning the construction and operation of the voluntarily movable artificial arm." He stressed the importance of the force-length diagram of muscle as determining performance of the musculo-mechanical system, and presented several diagrams obtained by Meyer on cinetized muscles.

Bethe clearly emphasized how this property might easily be overlooked because *in situ* muscles are constrained by skeletal arrangements to relatively limited sections of their force-length diagrams, and hence the loss of force with shortening is not readily manifest in common observation. It is unfortunate that recent works on cineplasty, such as Kessler's (2), not only overlook the force-length diagram, but erroneously imply that the muscle force is constant with shortening. He writes, "The work performed by contracting muscle follows the usual formula of: $W = F \times D$. . . . Thus, if a muscle has a physiological cross-section of 5 square centimeters, its tension strength would be 5×10 (the absolute strength) or 50 kilograms. If the muscle shortens 5 centimeters, work will then equal $50 \times .05$ or 2.5 kilogram-meters." It is clear from the computation in the last sentence that the tension is assumed to be constant over the range of muscle excursion.

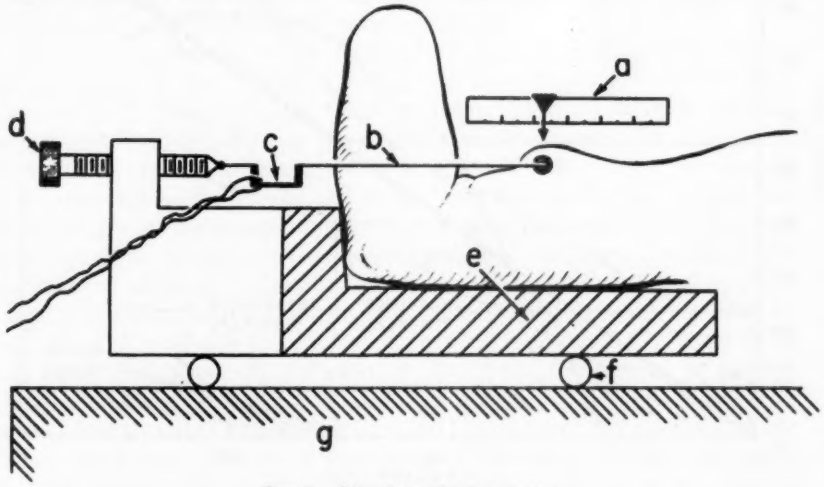


FIG. 2. Muscle testing apparatus.

a, tunnel displacement scale; *b*, cable from tunnel to strain gage; *c*, strain gage; *d*, displacement adjusting screw; *e*, arm cradle; *f*, rollers to prevent registration of pulls from the body; *g*, table.

In the experimental literature, force-length data are variable from muscle to muscle in the same species, and from species to species. Ralston et al. (4) have summarized the information on absolute force of cinetized muscles, expressed in kilograms per square centimeter of physiological cross-section. The values are quite low, for example 2.38 kg/cm^2 on the biceps, as compared with Haxton's (5) value of 3.9 kg/cm^2 for intact human calf muscles, probably because of the fact that the muscle tunnel does not as efficiently harness the fibers of the muscle as does the natural tendon of insertion. Force-length diagrams, thus, may vary considerably in their dimensions and form. This is shown by a comparison of Ralston's curve for the human pectoralis with Ramsey's

curve for single fibers (6) and with our data for human biceps, described below. Whether or not the form of these curves can be explained in terms of the relative amounts of non-contractile elastic elements and contractile elements, as suggested by Ralston et al., requires direct experimental proof which is now lacking. The force-length curve for a given muscle cannot be predicted accurately from any formulation now known, and, consequently, each muscle tunnel must be tested to establish its diagram.

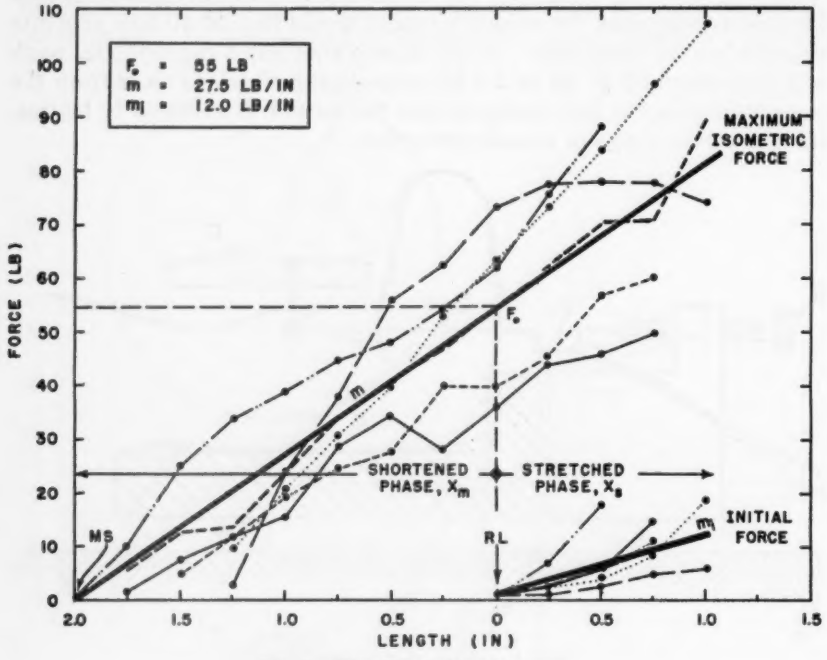


FIG. 3. Biceps force-length curves.

Experimental
individual curves
mean curves
RL, rest length
F_o, maximum isometric force at *RL*
MS, maximum shortening

Idealized
mean maximum isometric curve of slope *m*
m_i, slope of the mean initial force curve

2. *The Experimental Force-Length Diagram*

All measurements on human biceps were made with strain gage isometric dynamometers, with adequate precautions to insure that forces and displacements were measured relative to the origins of the muscle in the shoulder. A displacement adjusting device permitted the isometric contractions to be registered at many points in both shortening

and stretched phases (see Fig. 2). Initial forces were read prior to contraction in the stretched phase. All maximum isometric forces were obtained by instructing the subject to contract rapidly to maximum, then hold at this level for 1 to 2 seconds.

The average force-length curve was obtained from superimposed plots in which the individual curves were equated at rest length (RL). The initial force curve for each muscle was first plotted, the points joined, and the intercept of the abcissa at 1 lb. of force established at rest length. While zero initial force is the accepted definition of rest length, (and will be assumed in subsequent analysis) this is difficult to establish with certainty, owing to small spurious forces in the cables of the testing apparatus. The 1-lb. level is a practical one for prosthesis adjustment since, although it is below the threshold of perception of tension in the muscle, it insures against both slack in the muscle and slack in the control system. Having established RL for each curve, the data for all subjects can be referred to a common abcissa.

The results of force-length measurements on five biceps muscle tunnels are given in Fig. 3. The average maximum isometric curve is seen to be virtually linear throughout the entire range from extreme shortening to the tolerable extent of stretching. A similar trend was shown in two muscle curves reported by Sauerbruch. These plots, however, did not display the initial forces and hence they cannot be fully compared. Our average curve also agrees in its linearity with Ramsey's (6) idealized curve through the proximal shortening phase. It does not show the alteration of slope at extreme shortening as reported by Ramsey, but this may be a peculiarity of the single frog muscle fibers which he studied. Zchakaia (7), working with whole frog muscles, found the shortening excursion to be about 50 per cent of fiber length measured at resting length, and this seems to be true for a comparable portion of Ramsey's curve. It is possible to show approximate agreement between our mean biceps curve and cadaver measurements made by Weber (8). He measured biceps fiber length at full extension of the forearm, then at full flexion, and thus by difference defined the muscle excursion. The ratio of this excursion to rest length was found to be 0.59. The average rest length was 5.0 in. Assuming that our biceps have the same lengths of fibers, that the tunnels are situated at $\frac{1}{4}$ fiber length from the distal end, and that the ratio of excursion to extended length is 0.59, then the average biceps should have 2.2 in. of excursion. In Fig. 3 this is shown to be possible if an initial prestretch of about 3 lb. is applied. Since the value of prestretch in resting extended normal biceps is not known, these approximations cannot easily be checked. It can only be said that the orders of magnitude of the several quantities compared give reasonable agreement.

In the stretched phase the maximum isometric force curve continues its rise in four of the five muscles, one only turning downward. Thus,

the average may be said to continue the linear rise. The initial force curve pursues an irregular upward course, so that the net force between initial and maximum curves continues to increase over the range of measurement. This finding is in contradistinction to Ramsey's ideal net curve for isolated muscle fibers, and to Ralston's curves for pectoral and forearm flexor tunnels, where the net curve more or less clearly begins to decline early in the stretched phase.

3. The Load-Velocity Relation

It is well established from the work of Hill (9) and others that the velocity of muscle shortening is reduced as its tensile load is increased. The form of the Hill equation indicates that velocity and force are related by a rectangular hyperbola, but others disagree on the exact form of this relationship. Fenn and Marsh (10) found force to be an exponential function of velocity, while Ramsey (6) relates the velocity to shortening excursion (which in turn is a function of load), but finds agreement with Hill and Fenn only approximately. All such formulations must be strongly qualified in terms of the conditions of observation, that is, free loading *versus* after loading, type of fiber arrangement in the muscle concerned, and the amount and elasticity of sarcolemma and other connective tissue investing the muscle.

Fortunately, in the case of cineplastic prosthesis, the velocity of muscular contraction is of little concern. Neither in the natural hand nor in the artificial hand or hook does prehensile activity require any considerable velocity of muscle shortening under load. Assuming, for example, a shortening velocity of 4 cm/sec. the reduction of force from maximum isometric would be 23 per cent if calculated from the Fenn and Marsh equation for cat quadriceps, but only 7 per cent according to Ralston's data on human pectoralis. Typical tasks involve moderate rates of shortening in the prehension muscles. High forces come into play only when grasp is initiated, since usual objects are unyielding under the prehension forces necessary to manipulate them. Thus, isometric force of the muscle is the principal mechanical feature of concern in cineplasty.

4. The Effect of Elbow Angle

Another factor affecting the function of biceps muscle tunnels has been found in the case of below-elbow amputees where the force-length diagram varies with the degree of forearm flexion. Figure 4 presents average curves for three biceps cases at forearm extended and forearm flexed 90°. It is noted that extension reduces the force about 3 lb. at rest length and progressively more with shortening. The effect can be expressed mathematically by writing linear equations for the extended and flexed 90° curves. The difference equation expresses the extent to

which elbow extension reduces the maximum isometric force. The difference equation may be interpreted in terms of an elastic force, acting to oppose shortening, and having a coefficient of 11 lb/in.

It is difficult to find the explanation for this effect. In the Lebsche technique (1) the biceps tendon of insertion is transected and usually, as is known from the surgical record of two of these cases, the proximal end of the severed tendon is invaginated into the muscle to prevent possible reattachment. Moreover, surgical "freeing" of the biceps from lateral attachments with fascia or surrounding muscle elements is generally practiced, and was given special attention in two of the present cases. Nevertheless, the effect remains, but, since flexed positions varying from 70 to 120° are those of predominant use of prosthesis, it may be dismissed as of little practical concern.

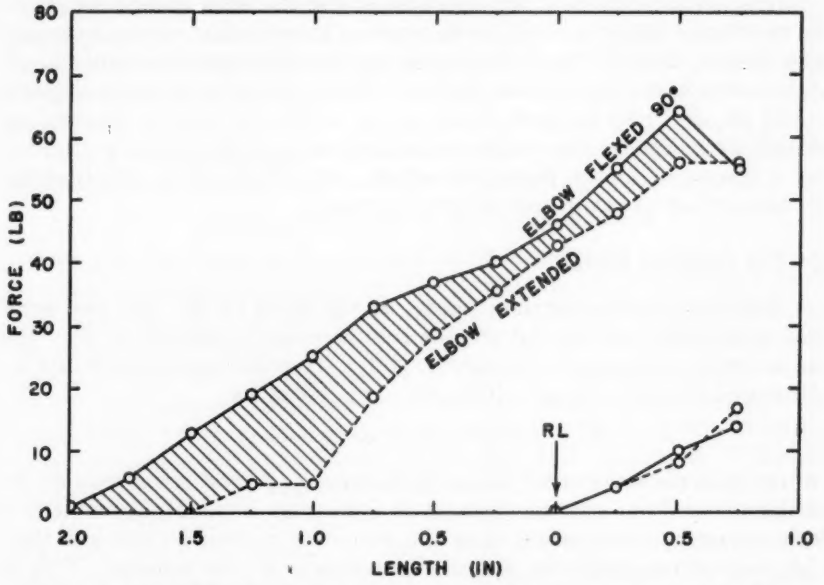


FIG. 4. Effect of elbow angle upon biceps force-length curve. Both curves are averages for three amputees. Shaded area indicates the loss in force-length area caused by elbow position.

THE IDEALIZED WORK POTENTIAL OF THE BICEPS

As a first step, straight lines can be drawn through the maximum and initial force curves as shown by lines on Fig. 3. Considering the variability in the individual curves no other assumption concerning the empirical shape of these curves is tenable. The area contained between these lines has the dimensions of work, and may therefore be taken to represent the work potential of the muscle.

1. The Shortened Phase

The triangular work area to the left of the ordinate at RL, that is, the shortened phase, engages our chief attention because it is the principal zone of utility. From a linear fit of slope m to the curve, the maximum isometric force F_m of the muscle at any shortening excursion x_m, measured from rest length, is

$$F_m = F_o - mx_m \tag{1}$$

where F_o is the maximum isometric force at rest length of the muscle. The total muscle work potential W_m with respect to rest length at any shortening x_m is given by the area of the trapezoid beneath the linear fit

$$W_m = F_o x_m - mx_m^2/2. \tag{2}$$

It is neither practical nor desirable to use the total muscle diagram. In the design analysis it will be shown that the selection of muscle excursion is controlled by the desired hook performance characteristics in all cases, except the multi-ratio device. Here, the total muscle diagram could theoretically be used; however, an arbitrary limit is imposed on muscle excursion by the consideration that extreme shortening is attended by a disproportionate feeling of effort. In this instance the limiting x_m is specified as two-thirds of total excursion.

2. The Stretched Phase

Turning to the stretched phase, at the right of RL, the net work potential is defined by the area of the trapezoid, bounded by RL, the initial and maximum force curves, and a stretched excursion value x_s, measured from rest length (Fig. 3). It is given by

$$W = x_s(F_o - 1) + x_s^2(m - m_i)/2$$

where m_i is the slope of the initial force curve. For practical reasons the utilization of the stretched phase is somewhat incidental, and it is a convenient approximation that the net force is usually not less than $(F_o - 1)$ throughout the stretched excursion of the muscle. This is true for the average diagram, and for three of the five individual muscles. Where this is not true, some reduction in available force will obtain, but this should cause no practical disadvantage.

TYPES OF MECHANICAL SYSTEMS

Four types of mechanical lever systems will be discussed which can be inserted between the muscle and the load to compensate for the loss in muscle force with excursion. These are as follows: Single Ratio System for the voluntary closing terminal device; Single Ratio System for the voluntary opening terminal device; Double Ratio System; and Multi Ratio System.

The single ratio system is typified by present day terminal device mechanisms for both hooks and hands, and can be of the voluntary closing or voluntary opening type. In the former, voluntary effort from the muscle closes the hook upon the object. The spring mechanism opens it, also returning the muscle to its starting length by the tension through the transmission cable. An automatic cam lock sets when prehension upon the object is complete and holds it without further muscular effort. A second pull unlocks the hook and allows the opening spring to operate. The automatic lock is henceforth disregarded because it does not enter into the analysis of the interrelation between the muscle force-length potential and hook force-excursion capacity.

In the voluntary opening terminal device, closing is effected by a spring or by rubber bands. Opening of the hook, prior to grasp, depends upon the voluntary contraction of the cinetized muscle.

The double ratio system functions with two lever ratios in time sequence. The first provides rapid closing of the hook fingers as the muscle shortens until the object is encountered. Then a second lever ratio is engaged which considerably increases the hook prehension force available.

The multi ratio system herein described provides a continuously changing force-excursion variation at the latter.

UTILITY REQUIREMENTS OF THE TERMINAL DEVICE

Present day amputee hooks, such as the one shown in Fig. 1, provide just one function, prehension (or pinch), although they serve such obvious utilitarian uses as pushing, hooking, etc The following dimensions are pertinent to design: x_h, F_h, F_s, K_1.[3] The first two of these refer to the hook tips, that is, excursion and force at the tips. Spring force, which, as measured, also contains dynamic friction losses in the hook, is expressed in terms of the mean force applied to the hook tips necessary to cause closure, with no object between the tips. In design, the spring coefficient is made as low as possible.

The hook ratio, K_1, is also approximately the ratio of operating "thumb" and hook length. In single ratio systems the variation of K_1 demanded by design considerations can simply be achieved in the device by selecting the point of cable attachment on the operating thumb which will give the desired ratio, K_1.

Three levels of hook force may be stated: Utility force—3 lb.; Medium force—7 lb.; and Maximum force—15 lb. These are based upon prehension requirements in the tasks of every day living (11). The utility level is also in part determined by the observation that amputees using common voluntary opening rubber-band loaded hooks habitually maintain prehension loadings in the range 2–4 lb.

Two ranges of hook excursion may also be defined: Utility excursion —1.5 in.; and Maximum excursion—3.25 in. Again, study of the tasks

[3] See Appendix B for nomenclature and design values.

of every day living shows that in common use, approximately 90 per cent of the time, only the utility excursion is required (11).

MECHANICAL SYSTEMS

1. Single Ratio System for the Voluntary Closing Device

Utilization of the Shortened Phase

The maximum force that can be applied by the muscle to the operating thumb of the voluntary closing device shown schematically in Fig. 5 is eF_m, where e is the efficiency of cable transmission. The forces acting at the hook tips are prehension F_h and the mean spring force F_s (which, in an actual device, must be expressed at the tips). All force equations in the sequel (for the single and multi ratio systems, and for both the quick-fan and cinch prehension phases of the double ratio system) are

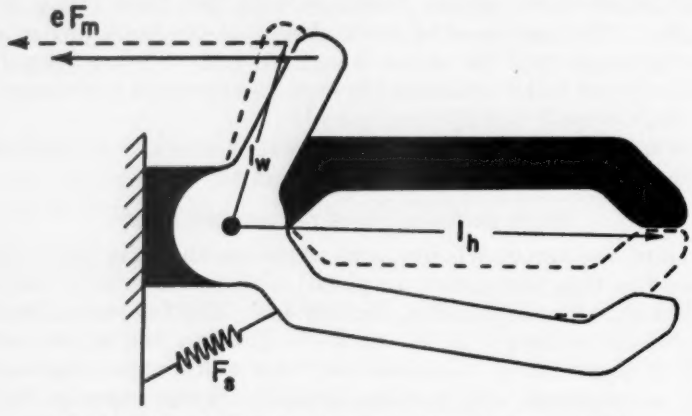


FIG. 5. Schematic diagram of voluntary closing hook mechanism.

written for the condition of static equilibrium of the mechanism, which exists during object prehension if we neglect the inertia forces contributed by the non-rigid deformation of the mechanism and object. A dynamical force balance prior to object prehension is not involved. For static equilibrium of the lever, we have (cf. Eq. 16, Appendix A)

$$F_h = K_1 e F_m - F_s$$

and using Eq. 1 with $x_m = c_1 K_1 x_h$ we get

$$F_h = K_1 e F_s - K_1^2 em\, c_1 x_h - F_s \tag{3}$$

where $K_1 = bl_w/l_h$, l_w and l_h being the lengths shown in Fig. 5. b and c_1 are correction factors which depend on the angular incidence of the force at the operating thumb (see Appendix A). x_h is the hook tip excursion, measured along the chord from the fully open (initial) position.

It is evident that several of the quantities in Eq. 3 such as the muscle values F_o and m, are fixed by the nature of the muscle (assuming of course it has been trained to an optimal level); others depend on choice. Of these the lever ratio, K_1, is the chief design variable. Here, an analytical procedure may be applied which determines, for a specified muscle curve and a specified hook excursion, $\bar{x}_h$, what value of K_1 gives the maximum force at the hook during that part of the closing cycle when its force would be at the lowest. In other words, it determines the highest possible hook force at the end of its power stroke, that is, closure. Practically, this assures that hook force does not diminish during closing to a level which is incompatible with effective prehension of thin but heavy objects. Maximizing Eq. 3 with respect to K_1, we obtain, since c_1 is preselected, $K_1 = F_o/2_m c_1 \bar{x}_h$ and $x_m = F_o x_h/2m\bar{x}_h$. The first result defines the design value of K_1 which gives a maximum prehension F_h at a preselected hook excursion $\bar{x}_h$ with specified muscle and cable system characteristics. The second equation yields the simple result that a muscle excursion equal to half the range from RL to maximum shortening gives the maximum F_h for any selected x_h.

It is evident that with all other quantities specified, F_h and x_h vary oppositely; hence the practical choice is to obtain the best combination for hook performance in terms of the requirements stated in the preceding section.

Utilization of Both Shortened and Stretched Phase

With the single ratio transmission system, the stretched phase may also be harnessed. Here, it is desirable to use a device such as the Army Prosthetics Research Laboratory voluntary closing hook, which is provided with two ranges of excursion, *half* and *full*, 1.5 and 3.25 in., respectively. These positions are selected by setting a manual switch. The half range accommodates at least 80 per cent of amputee use, and the full range is needed only for occasional large objects. It is then possible to devote the muscle shortening phase to operation over half range of the hook, and the stretched phase to the additional half giving the full range. To do this, the design procedure for the stretched phase is followed, using $\bar{x}_h = 1.5$ in. and all other muscle values. The amputee then habitually carries the hook at the *half* position, which gives him sufficient prehension opening for the majority of tasks. But when, on occasion, he needs full hook excursion, he shifts to *full* and lets the hook spring stretch the muscle until either full opening is obtained or a point on the initial force curve is reached equal to the spring force acting on the muscle. As noted from the average force-length diagram, the elastic force given by the initial force curve may be expressed by a linear equation, $F_i = 1 + m_i x_s$. Setting this equal to the hook spring force transmitted back to the muscle, that is, eK_1F_s, the stretch given

to the muscle is $x_s = (eK_1F_s - 1)/m_t$. For typical mechanisms, x_s is in the range 0.5 to 1.0 in. When this may not fully open the hook, the amputee completes the opening by prying open the hook on the object to be manipulated, or, if he is unilateral, by reaching over and forcing the hook open with his natural hand.

Examples and Check Data

Three examples illustrate the design process. Given, for all three, muscle and mechanical characteristics F_o, m, F_s, e, x_h from Appendix B and $c_1 = 1$ (see Appendix A) then for the various chosen hook excursions, the results are shown in Table I. Plans A and B utilize the

TABLE I.—*Calculated Ratios and Hook Forces.*

Utilization	$\bar{x}_h$	K_1	F_h	W_m
A. Shortened Phase	3.25	0.31	3.7	41.2
B. Shortened Phase	2.00	0.5	8.0	41.2
C. Shortened and Stretched Phases	1.50	0.67	11.6	77.2

shortened phase only, and can extract muscle work equal to 41.2 in-lb. according to Eq. 2. In B, selection of the smaller $\bar{x}_h$ permits a higher F_h. In *C* the selection of *half* hook excursion yields the highest hook force, which, it has been shown, will be even higher in the stretched phase for the occasional use on objects in the range, 1.5 to 3.0 in. In this case the muscle work, potentially usable, is almost double that of the preceding cases.

The performance of a system utilizing Plan A is shown in the output diagram of Fig. 11*a*. The proof of the design procedure consists in a final prehension test to check the forces obtained against those calculated from Eq. 3. The results for five amputees are given in Table II. In general, agreement is within 1 lb. which is satisfactory for the precision with which the various quantities can be measured.

TABLE II.—*Comparison of Calculated and Experimental Prehension Forces.*

Amputee	Muscle Tunnel	APRL Device	Muscle Values F_s, lb.	m, lb./in.	K	Hook Opening, in.	Preh. Forces, lb. Calc.	Exptl.
D. W.	Biceps	Hook	50	28.6	0.5	0.33	10.5	11.0
						0.82	8.4	8.0
C. M	Triceps[1]	Hook	50	38.5	0.33	0.66	8.4	9.0
						1.0	7.4	7.5
						1.6	5.5	4.0
R. W.	Biceps	Hook	68	24.7	0.33	1.1	10.7	12.5
						1.6	9.9	11.0
						2.1	9.0	9.0
J. F.	Biceps	Hand[1]	56	25.0	0.86	1.0	13.7	11.3
L. Q.	Biceps	Hook	67	36.4	0.25	1.0	6.6	10.0

[1] The triceps of amputee C. M. and the hand worn by amputee J. F. are incorporated in design calculations identical with those for the biceps and the hook.

2. Single Ratio System for the Voluntary Opening Device

With this device, shown schematically in Fig. 6, closing is effected by a spring or by rubber bands, the forces of which comprise the F_h. Opening of the hook, prior to grasp, depends upon the voluntary contraction of the cinetized muscle.

The design procedures respecting the muscle characteristics, and the selection of K_1 are similar to those for the voluntary closing device. However, they differ in that the spring force does not oppose the muscle in prehension: the muscle work is transferred to potential energy in the spring in the opening phase, then to spring work in the closing phase. Assuming no friction the equations may be written,

$$\text{Voluntary opening phase: } F_m = F_s'/e\,K_1$$
$$\text{Spring closing phase: } F_h = F_s'$$

where F_s' is the mean hook spring force measured at the tips during closure. These give,

$$F_h = e\,K_1F_o - ec_1K_1^2m\,x_h. \tag{4}$$

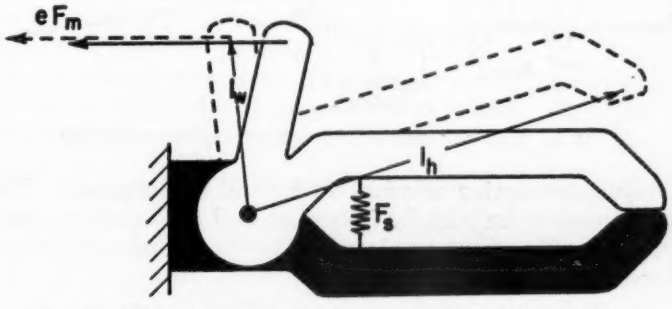


FIG. 6. Schematic diagram of voluntary opening hook mechanism.

Selecting as design requirement the maximum prehension (spring force) at some preselected hook excursion $\bar{x}_h$ we obtain, as before, $K_1 = F_o/2mc_1\bar{x}_h$.

Taking as an example, data for the voluntary closing hook used in Table I, we calculate: for the 3.25-in. hook excursion, $F_h = 6.7$ lb; and for 2.0-in. excursion, $F_h = 11.0$ lb. The output diagram (Fig. 11*b*) shows the essential characteristic of this device, that it yields a constant force throughout the range of hook opening.

3. Double Ratio System

This type of system, as shown diagrammatically in Fig. 7, provides rapid closing of the hook fingers as the muscle shortens, designated "quick-fan" phase, until the object is encountered. The pulley system

shown is free to operate during this phase and the lever ratio obtained is that of the terminal device. Then, the tension in the control system compresses a spring, locking the pulley system and throwing into action an additional lever system (lever ratio K_2) which considerably increases the mechanical advantage and therefore the hook prehension force. This is called the "cinch" phase. For the analysis of this system only the shortened phase of the muscle will be utilized, and only application

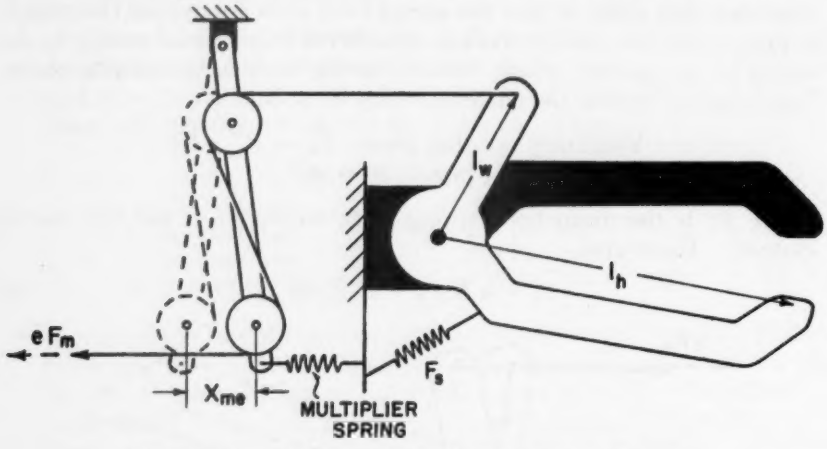


FIG. 7. Schematic diagram of double-ratio system mechanism.

to the voluntary closing terminal device will be discussed. The latter will be assumed to be initially fully open and the muscle at rest length position ($x_m = 0$). Since total usable muscle excursion is limited, additional considerations, required in this system, are:

x_{hd} = an equivalent finger tip excursion due to deformation of the fingers, total mechanism, and object, during cinch prehension.
x_{me} = the muscle excursion necessary to engage the multiplier mechanism.

Design Equations

The muscle acts to quick-fan the fingers through x_h' to the object, where we take $x_h' = 0$ at rest length, engage the multiplier mechanism, introducing the multiplication ratio K_2, and, in cinching on the object, take up the deformation in the system. The excursion balance for this process may be written at the muscle as

$$c_1K_1x_h' + c_1c_2K_1K_2x_{hd} + x_{me} = x_m \tag{5}$$

where we define the ratio K_2c_2 by the input excursion $x_m = c_1c_2K_1K_2x_h$, to the multiplier during cinch, where c_2, like c_1, is an angular correction

factor (see Appendix A), During cinch-prehension, the force available at the hoop tips is

$$F_{hc} = K_1K_2eF_m - K_1F_{s2} - F_s \tag{6}$$

where F_{s2} is the mean spring force of the multiplier, as measured at the output end.

In designing the mechanical system, a desirable requirement, as in the single ratio system, is maximum prehension at some preselected hook excursion $\bar{x}_h'$ with specified muscle and cable system characteristics and specified maximum deformation and engagement excursions $\bar{x}_{hd}$, $\bar{x}_{me}$. The design problem becomes that of the selection of practical values of K_1, K_2, F_s and F_{s2} to satisfy this requirement and yield an adequate level of prehension F_{hc} during cinch. Two additional conditions on the magnitudes of the spring loadings are necessary. During quick-fan we must have

$$F_s/K_1 < eF_m < F_{s2} \tag{7}$$

so that the difference $K_1eF_m - F_s$ provides a small net force at the hook suitable for light prehension tasks without multiplier action. Apart from Eqs. 5–7, values for F_s and F_{s2} are not arbitrary, but will usually be approximately known from the practical considerations of the device.

In order to determine values of quick-fan and cinch ratios which satisfy the design requirement, we proceed as follows. Combine Eqs. 1, 5, and 6 to get

$$F_{hc} = aK_1K_2 - c_1c_2K_1^2K_2^2\,emx_{hd} - c_1K_1^2K_2\,emx_h' - K_1F_{s2} - F_s \tag{8}$$

where $a = e(F_o - mx_{me})$. Applying the necessary conditions for a maximum, $\partial F_{hc}/\partial K_1 = \partial F_{hc}/\partial K_2 = 0$, we obtain the ratios

$$K_1 = \bar{a}/em\,c_1(2c_2\bar{x}_{hd}\,K_2 + \bar{x}_h') \tag{9}$$

$$K_2 = -\,F_{s2}\bar{x}_h'/(\bar{a}\bar{x}_h' + 2c_2\bar{x}_{hd}F_{s2}) \tag{10}$$

where $\bar{a} = e(F_o - m\bar{x}_{me})$. From Eq. 10, K_2 is seen to be physically unrealizable and it can be shown that, for the feasible range of the parameters, Eq. 8 has niether a maximum nor a minimum with respect to K_1 and K_2.

Since Eq. 7 must always be satisfied, the rate of quick-fan will almost certainly be adequate. Hence, if we regard K_1 preselected, Eq. 9 determines the values of cinch ratio K_2 which otherwise fulfills the design requirement. For convenient use, Eq. 9 and the design (maximum) muscle excursion may be written as

$$c_1K_1\bar{x}_h' + 2c_1c_2K_1K_2\bar{x}_{hd} = F_o/m - \bar{x}_{me} \tag{11}$$

$$\bar{x}_m = (F_o/m + \bar{x}_{me} + c_1K_1\bar{x}_h')/2. \tag{12}$$

If we set $K_2 = c_2 = 1$, $x_{me} = x_{hd} = F_{s2} = 0$ in (8) we obtain the pre-

hension force available during quick fan (without multiplier action) as

$$F_h = eF_oK_1 - c_1K_1^2\, em\, x_h' - F_s. \tag{13}$$

Construction of the Design Chart

The design of the system is now completely determined by Eqs. 7, 8, 11, 12, and 13, and may be carried out graphically as shown in Fig. 8. For convenience in plotting, Eqs. 8, 11, and 12 may be combined to express the design prehension force during cinch as

$$F_{hc} = e[F_o - m(K_1c_1\bar{x}_h' + \bar{x}_{mc})]^2/4c_1c_2m\bar{x}_{hd} - K_1F_{s2} - F_s. \tag{14}$$

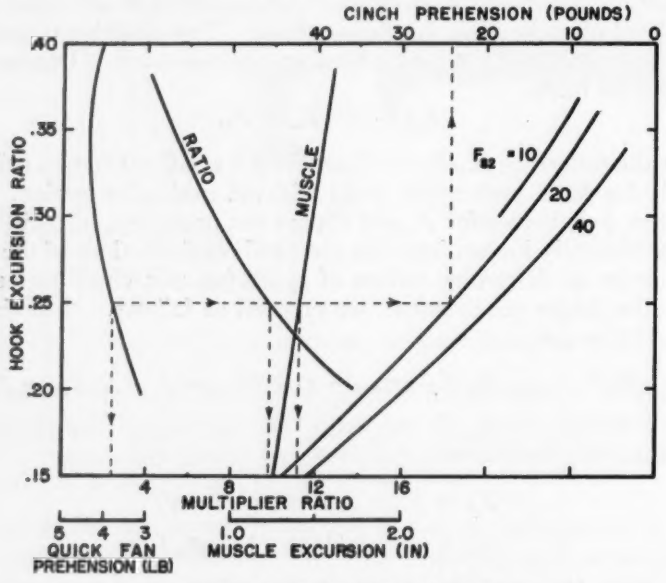


FIG. 8. Design chart, double-ratio system.

With many variables to be considered, a completely general formulation in chart form has not been attempted. The chart, Fig. 8, is offered as an example of the relationships between a limited number of variables. The following have been introduced as constants: F_o, m, $\bar{x}_h'$, e, F_s, c_1, c_2, $\bar{x}_{hd}$ and $\bar{x}_{mc}$ (see Appendix B).

In preparing the chart, spring conditions (7) are satisfied at the outset. Thus Eq. 7 requires that $K_1 > 0.078$ and that $K_1F_{s2} > 3$, and these limits are indicated on the chart.

An example illustrates the use of the chart. It is required to determine practical values of K_1, K_2 and F_{s2} such that: (*a*) cinch-prehension is at least 20 lb.; (*b*) quick-fan prehension is adequate for light duty, that is, greater than 3 lb.; and (*c*) muscle excursion is near the physio-

logical limit of 1.3 in. as previously defined. The problem is solved, as indicated by the arrows, with the following design values:

$K_1 = 0.25$	$F_{s2} = 20$ lb.	$F_h = 2.9$ lb.
$K_2 = 9.7$	$x_m = 1.40$ in.	$F_{hc} = 24.3$ lb.

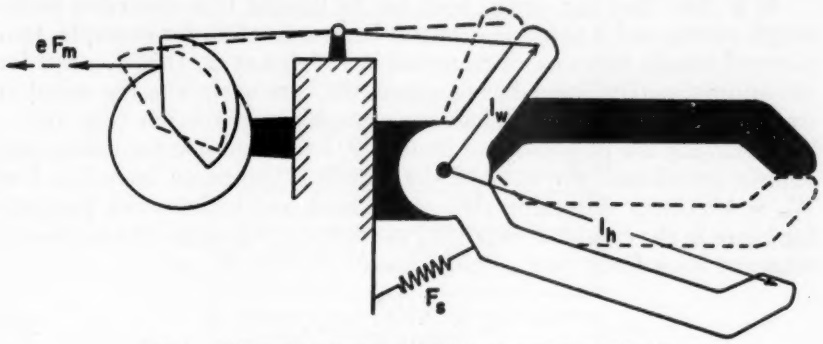


FIG. 9. Schematic diagram of multi-ratio system mechanism.

4. Multi-Ratio System

Another mode of operation of the terminal device, is one which maintains a constant force at the hook throughout the excursion of the muscle. To accomplish this a continuously changing transmission ratio is necessary between the muscle and the terminal device.

The simplest example of a multi-ratio system (see Fig. 9) is a cam device inter-relating muscle and wrist cable excursions in the following

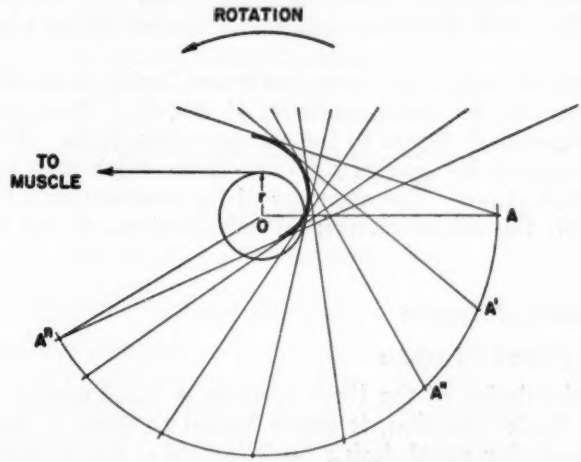


FIG. 10. Cam design for multi-ratio system.

way. The muscle cable is made to pass over a pulley and is fastened to its perimeter. To the pulley is integrally attached a cam pulley for the hook cable. The cam curve is designed with radii proportional to the ordinates of the muscle force-length curve. Thus, if the force in the muscle cable follows the latter, that in the hook cable will be constant.

It is clear that the design need not be limited to a linearized force-length curve, and a suitable cam can be constructed, for example, to a pectoral muscle curve as diagrammed in Ralston et al. (1949). But for the approximately linear biceps curve, the cam surface is the spiral of Archimedes; it is easily obtained by a graphic construction (Fig. 10).

Assuming the physiological limit of 2/3 total muscle excursion, previously mentioned, the work of the muscle is computed from Eq. 2 as $W_m = 4F_o^2/9m$. Equating eW_m to the hook and spring work (neglecting losses in the cam) and regarding c_1 constant, we obtain the maximum constant hook force over a design hook excursion $\bar{x}_h$, as

$$F_h = \frac{4eF_o^2}{9c_1m\bar{x}_h} - F_s \tag{15}$$

which is 9.00 lb. using values in Appendix B.

The next step is to sub-divide x_m into suitably small intervals, say seven, and at these sub-divisions, to compute the ratios $eF_mK_1/(F_s + F_h)$. Then a series of concentric circles should be drawn with radii proportional to these ratios, Fig. 10. The largest circle is made a convenient and practical size as determined by the space limitations on the arm. Let point A represent the location of a retainer on the forearm at the wrist, selected at a convenient distance from O, through which the wrist cable will pass. The contraction of the tunnel will rotate the cam in the direction indicated, wrapping wrist cable, and unwrapping the muscle pulley cable through an angle of $180x_m/\pi r$, where r is the pulley radius.

Dividing this angle into seven parts and laying these off clockwise, beginning at OA, we obtain points A, A', A'', etc. From each of these points, tangents are drawn to the corresponding circle. The envelope of these tangents determines the cam curve which may be drawn in with a french curve. The accuracy of its construction, of course, increases with the initial number of sub-divisions of the force-length curve.

5. *Comparison of Systems*

Hook Output Diagrams

Since the design of the three systems is based upon a preselected maximum hook excursion, it seems logical to make a comparison of systems assuming equal design hook excursion for all three. Such a comparison is illustrated in Fig. 11 which is drawn for $K_1 = 0.31$ and

values of the parameters given in Appendix B. Ratios for single and double systems having been selected in design, hook output force is then given by Eqs. 3, 8 and 13, where the variables are now x_h, x_h' and x_{hd}, and x_h', respectively. Output force from the multi-ratio and voluntary opening devices are computed from Eqs. 15 and 4, respectively.

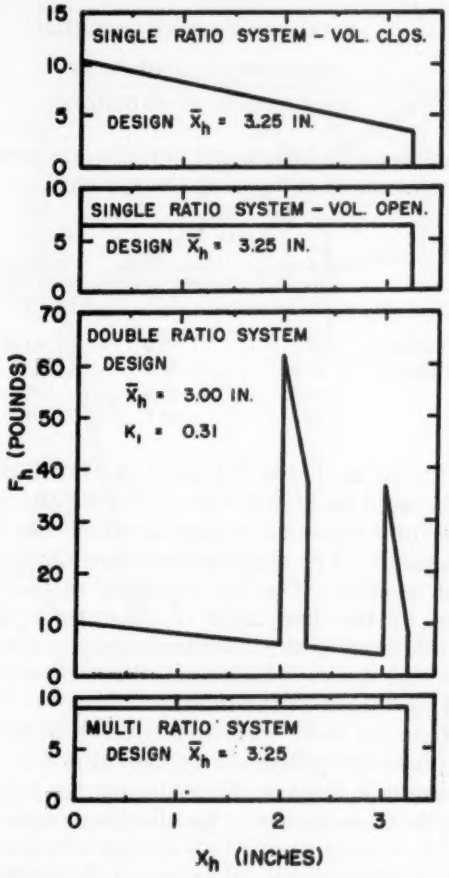


FIG. 11. Comparative output diagrams.

6. *Comparison of Force, Work and Efficiency*

At corresponding submaximal excursions, x_h, (K_1, K_2 fixed in design) it is seen that the double system will deliver appreciably greater hook forces during the cinch-prehension phase. For example, the cinch-prehension force available at 2.0-in. excursion is shown. The double ratio system, designed to some specified hook excursion, has potentially

greater prehension utility at all intermediate hook excursions, because, in different cycles of use, the high cinch forces can be developed at any position of hook opening.

The comparative effectiveness of the systems may be stated by two ratios:

$$E_1 = \frac{\text{total output hook work}}{\text{total muscle work potential}}$$

$$E_2 = \frac{\text{total output hook work}}{\text{total muscle work utilized}}$$

These values, together with inputs and outputs, are present in Table III to afford another means of comparing the systems.

TABLE III.

System	Total Hook Work, in.-lb.	Total Muscle Work Potential, in.-lb.	Total Muscle Work Utilized, in.-lb.	E_1, %	E_2, %
Single-ratio					
Voluntary Closing Device	23.2	55.0	41.25	42.2	56.2
Voluntary Opening Device	22.0	55.0	27.5	40.0	80.0
Double ratio	25.35	55.0	51.4	46.1	49.3
Multi-ratio	29.3	55.0	48.9	53.3	60.0

The values for E_1 in Table III show the multi-ratio system to be highest, and this could be higher were it not for the arbitrary limit on x_m of two-thirds total muscular excursion which has been assumed on physiological grounds. The single systems are lowest, and about equal, but for different reasons. The low efficiency of the voluntary closing system is caused by the dissipation of muscular work in the opening spring; the low efficiency of the voluntary opening system is based upon the peculiarity of the device, which can utilize only a rectangular section of the potential work area of the muscle.

The ratio of output hook work to the total muscle work utilized in the design, E_2, ranks the systems in a different order. Here, the voluntary opening system is highest since the energy losses are limited to those in the cable transmission. In all other cases, spring losses are added, the double system having two springs which oppose the muscle.

It is evident that no single criterion can be used in evaluating the systems. They vary in complexity, and therefore in the possibility of designing feasible, durable and effective mechanisms, as well as theoretical effectiveness based upon the proportion of the muscle work potential that is utilized. Final selection for best results in a given case will depend upon the judgment of the prosthetist and the engineer.

APPENDIX A

CERTAIN PRACTICAL CORRECTIONS IN RATIO SYSTEM DESIGN

The purpose of this Appendix is to investigate the effect on lever ratio, spring and prehension forces, of the angular incidence of the forces acting on typical single and double ratio systems.

In the single ratio system of Fig. 12, let F_w and F_h be for forces at W (horizontal) and H

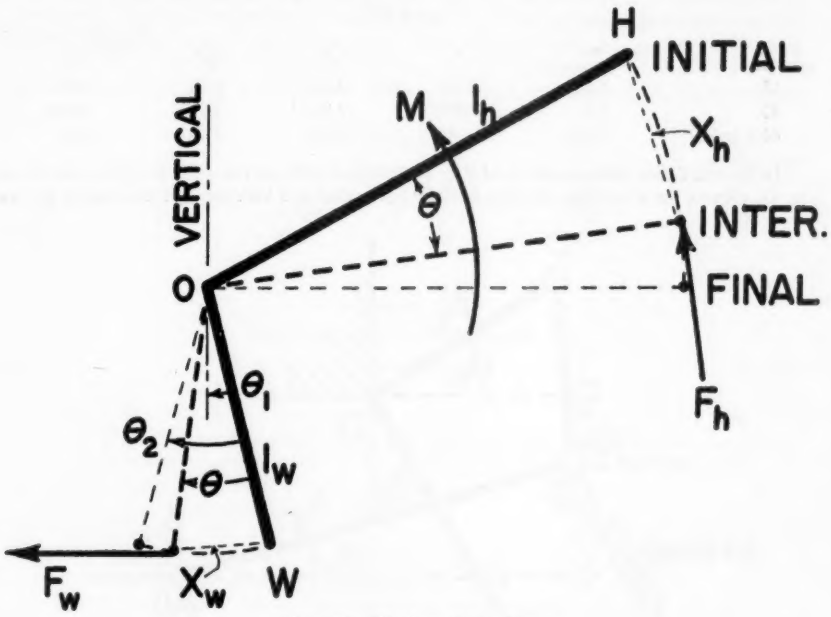


FIG. 12. Single-ratio system.

(along the chord), respectively, and M be the moment due to the hook helical spring and to friction. For static equilibrium of the levers OH and OW, we have

$$F_w l_w \cos(\theta - \theta_1) = M + F_h l_h \cos[(\theta - \theta_2)/2]$$

where $l_h = OH$, $l_w = OW$. θ_1, θ_2 and θ define, with respect to the initial position of OW, its final position, the position of a reference axis normal to F_w, and the angle of rotation of the levers, respectively.

Hence we may write

$$F_h = K_1 F_w - F_s \tag{16}$$

where

$$K_1 = b l_w / l_h, \quad b = \cos(\theta - \theta_1)/\cos[(\theta - \theta_2)/2]$$
$$F_s = M/l_h \cos[(\theta - \theta_2)/2] \tag{17}$$

from which we see that excursion corrections are necessary on both the ratio and the spring force.

From Fig. 12 and Eq. 17, the excursion ratio

$$\frac{x_w}{x_h} = \frac{l_w[\sin\theta_1 + \sin(\theta - \theta_1)]}{2 l_h \sin(\theta/2)}$$

where x_w and x_h are the horizontal and chord wise excursions of W and H, respectively, can be related to K_1 by a correction factor c_1 defined as

$$c_1 = \frac{x_w/x_h}{K_1} = \frac{\cos[(\theta - \theta_2)/2]}{2\cos(\theta - \theta_1)\sin(\theta/2)}[\sin\theta_1 + \sin(\theta - \theta_1)].$$

Table IV shows the effect of c_1 on prehension F_h, Eq. 3, for the typical values $\theta_2 = 2\theta_1$, $l_h = 4.25$ in., $M/l_h = 3$ lb., $K_1 = 0.31$, and other values as listed in Appendix B.

TABLE IV.

θ, deg.	x_h, in.	c_1	F_s, lb.	F_h, lb.	Error of Uncorrected Analysis ($c_1 = 1$), %
15	1.11	0.944	3.10	8.24	0.36
30	2.2	0.990	3.02	5.97	0.50
44.9 (max)	3.25	1.085	3.00	3.18	18.2

In the multiplier linkage system of Fig. 13 (which is without the quick fan phase shown in Fig. 7), assume for simplicity all links initially horizontal and vertical, and frictionless hinges

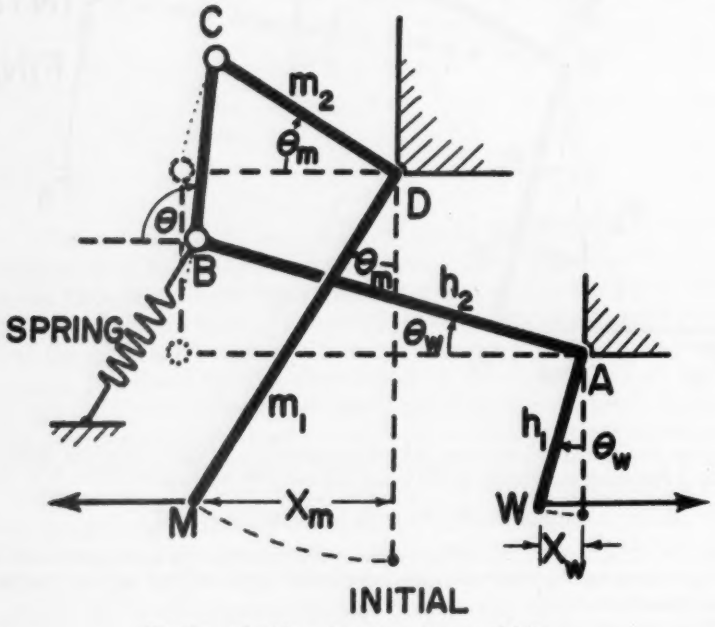


FIG. 13. Double ratio system, force multiplier.

at A, B, C, and D. If F_w and F_m denote the horizontal forces applied at W and M, respectively, we have, for static equilibrium

$$F_w = K_2 F_m - F_{s2}$$

where

$$K_2 = \frac{h_2 m_1}{h_1 m_2}$$

is the multiplier force ratio

$$F_{s2} = \frac{h_2 F_{s1}}{h_1 \cos\theta_m}$$

where F_{sn} is the component of spring force normal to link CD, which varies with θ_m, the angle of rotation DM and DC, in a manner depending upon its arrangement in a given design. Thus an excursion correction is necessary on the spring force F_{s2}. As in the single ratio system, the excursion ratio

$$\frac{x_m}{x_w} = \frac{m_1 \sin \theta_m}{h_1 \sin \theta_w}$$

where x_m and x_w are the horizontal excursions of M and W, respectively, can be related to K_2 by a correction factor c_2 defined as $c_2 = (x_m/x_w)/K_2$. In a typical design, the rotation of link BC is negligible, and a good approximation is $m_2 \sin \theta_m = h_2 \sin \theta_w$, so that we find $c_2 = 1$.

Table V shows the effect of correction factor c_1 on cinch prehension F_{hc}, Eq. 8, for typical values as before. We take a mean $F_{s2} = 20$ lb. As noted, variations in F_{s2} depend upon a given design.

TABLE V.

θ_h, deg.	x_h', in.	c_1	F_o, lb.	F_h, lb.	Error of Uncorrected Analysis ($c_1 = 1$), %
23.5	1.5	0.966	3.025	37.6	3.92
45	3.0	1.085	3.00	8.64	67.3

APPENDIX B

NOTATION AND DESIGN VALUES

Symbol	Definition	Equation
a	$a = e(F_o - mx_{mo})$	8
$\bar{a}$	$\bar{a} = e(F_o - m\bar{x}_{mo})$	9
b, c_1	$b = K_1/(l_w/l_h)$, $c_1 = (x_w/x_h)/K_1$ correction factors which depend on the angular incidence of the force applied at the operating thumb of the single ratio system	3
c_2	$c_2 = (x_m/x_w)/K_2$ angular correction factor	5
e	efficiency of cable transmission system design value, 0.80	3
E_1	total output hook work / total muscle work potential	
E_2	total output hook work / total muscle work utilized	
F_h	force between hook tips, single and multi-systems, quick fan of double system	
F_{hc}	force between hook tips, cinch prehension	6
$\bar{F}_{hc}$	design value of F_{hc}	14
F_i	initial (passive) force in the stretched muscle	
F_m	maximum isometric force of the muscle at any excursion	1
F_o	Maximum isometric force at rest length of the muscle design value, 55 lb.	1
F_s	mean hook spring force measured at the hook tips design value, 3 lb.	
F_s'	mean voluntary opening hook spring force measured at the tips during closure	
F_{sn}	component of the multiplier spring force normal to link CD in Fig. 13	
F_{s2}	mean spring force of the multiplier, measured at the output end	
F_w	horizontal force at W in the single ratio system of Fig. 12	
h_1, h_2	lever lengths in the multiplier linkage system of Fig. 13	
K_1	hook force ratio $K_1 = bl_w/l_h = (F_h + F_s)/F_w$	3, 16
K_2	multiplier force ratio $K_2 = (F_w + F_{s2})/F_m = h_2m_1/h_1m_2$	16
l_h, l_w	lever lengths OH, OW in the single ratio system of Fig. 12	
m	slope of the maximum force curve design value, 27.5 lb/in.	1
m_1, m_2	lever lengths in the multiplier linkage system of Fig. 13	
M	moment due to the helical spring and to friction in the single ratio system of Fig. 12	

Symbol	Definition	Equation
m_i	slope of the initial force curve design value, 12.0 lb/in.	
r	radius of the muscle pulley in the multi-ratio system	
x_h	hook tip (chord wise) excursion relative to the fully open position in the voluntary closing device (muscle at rest length)	3
$\bar{x}_h$	design value of x_h design value, 3.25 in.	
x_h'	hook tip excursion, quick fan	5
$\bar{x}_h'$	design value of x_h' design value, 3.00 in.	9
x_{hd}	equivalent hook tip excursion due to deformation of the fingers, total mechanism, and object during cinch prehension	5
$\bar{x}_{hd}$	design value of x_{hd} design value, 0.25 in.	9
x_m	muscle excursion from rest length, shortened phase	1
$\bar{x}_m$	design value of x_m	12
x_{me}	muscle excursion necessary to engage the multiplier mechanism	5
$\bar{x}_{me}$	design value of x_{me} design value, 0.04 in.	10
x_s	muscle excursion from rest length, stretched phase	
x_w	horizontal excursion of W in the single ratio system of Fig. 12	
W_m	total muscle work potential relative to rest length, shortened phase	
$\theta_1, \theta_2, \theta$	define, with respect to the initial position of lever OW, its final position, the position of a reference axis normal to F_w, and the angle of rotation of the levers, respectively, in the single ratio system of Fig. 12	
θ_m	angle of rotation of links DM and DC in the multiplier linkage system of Fig. 13	
θ_w	angle of rotation of links AB and AW in the multiplier linkage system of Fig. 13	

REFERENCES

(1) F. SAUERBRUCH, "Die willkurlich bewegbare Kunstliche Hand.," Berlin, J. Springer, 1923.
(2) H. H. KESSLER, "Cineplasty," Springfield (Ill.), Thomas, 1947.
(3) R. H. ALLDREDGE, *J. Bone and Joint Surg.*, Vol. 30A, p. 359 (1948).
(4) M. J. RALSTON, M. J. POLISSAR, V. I. INMAN AND J. R. CLOSE, *J. Appl. Physiol.*, Vol. 1, p. 526 (1949).
(5) H. A. HAXTON, *J. Physiol.*, Vol. 103, p. 267 (1944).
(6) R. W. RAMSEY, "Muscle: Physics," in "Medical Physics," edited by Otto Glasser, Chicago, Year Book Publishers, 1944, p. 784.
(7) M. ZCHAKAIA, *Pflugers Arch. f. d. ges. Physiol.*, Vol. 209, p. 753 (1925).
(8) E. F. WEBER, *Berichte der Sachs. Gesellschaft der Wissenschaften Math.-Phys. Klasse*, 1851, p. 63.
(9) A. V. HILL, *Proc. Roy. Soc.*, London, s. B 126, p. 136 (1938).
(10) W. O. FENN AND B. S. MARSH, *J. Physiol.*, Vol. 95, p. 277 (1935).
(11) F. S. STRONG, editor, "Human Limbs and Their Substitutes," New York, McGraw-Hill, in press.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS*

FATIGUE PROPERTIES OF MUSIC WIRE AND SPRINGS

An investigation of the fatigue properties of music wire and springs, which is now under way at the National Bureau of Standards, has resulted in the development of a reversed bending analysis method for predicting the approximate fatigue strength of helical springs wound from music wire. The study, which is being conducted by J. A. Bennett, H. C. Burnett and C. L. Stangaitis of the NBS mechanical metallurgy laboratory, has also yielded information about the mechanism of failure of wire springs.[1]

Many ordnance devices such as machine guns and small arms are dependent on helical springs for their operation. These springs operate over a very large stress range and must maintain their original strength through thousands of cycles. Music wire is most frequently used for springs in ordnance devices because it is the strongest engineering material available. Small-diameter wire of this type is produced commercially with a tensile strength as high as 450,000 psi. The reversed-bending study, made on four types of wire, is the first phase of the Bureau's investigation of helical springs. The work is sponsored by the Army Ordnance Corps.

In the NBS investigation reversed bending fatigue studies were made using two types of testing machines. One of these was designed and constructed at the Bureau; the other was the Hunter wire fatigue tester. The NBS machine utilizes a rotating strut but differs somewhat from other machines of this type. Both machines operate on the principle that a rotating curved wire must reverse its points of maximum compression and tension once each revolution. Approximately 50 specimens of four types of wire were studied under reversed bending in the Hunter machine, and 100 specimens of each type in the NBS machine. When results from the two machines were correlated, no consistent difference in data was found.

Fatigue studies of short compression springs were made in another type of machine designed at the Bureau. In this device an electric motor and adjustable eccentric are attached to one end of a steel plate which is pivoted at its midpoint. Eight springs, four at each end, are mounted between the pivoted plate and a second fixed plate approximately two inches below. The four springs at each end are positioned

* Communicated by the Director.

[1] "Endurance of Helical Springs Related to Properties of the Wire," by H. C. Burnett and C. L. Stangaitis, *Metal Progress*, Vol. 64 (September 1953).

at the corners of a theoretical square. This permits the eight springs to be stressed simultaneously at two levels. Stress levels are computed by measuring the change in pitch of each spring when in the no-load minimum-, and maximum-load positions.

In order to provide a comparison between the results of the reversed bending studies and the compression tests, the data obtained were used to prepare tables that give, for various life times, the ratio between the stress range in the springs and the stress amplitude in the wire. These turned out to be similar for all of the four types of wire tested. The NBS data indicate that reversed bending fatigue analysis of music wire will give the approximate fatigue strength at high stress levels of helical springs wound from that wire. However, the correlation was not sufficiently good to differentiate between samples of similar wire.

In the course of the investigation a study was made of the mode of fracture of the springs. In a helical spring loaded in tension or compression the wire is actually twisted. Consequently, there are shear stresses in the wire which are parallel and perpendicular to its length, and the tensile stress is at an angle of 45° to these. Observation of the fractures showed that in almost all cases a fatigue crack had started on a longitudinal shear plane and progressed for some distance along the wire before a crack normal to the tensile stress started. Fracture of the wire occurred when the tensile crack had progressed only a short distance. These observations were verified by microscopic examination of a cross section of the wire taken from a fracture. The discovery that fatigue cracks start on a longitudinal shear plane explains one type of failure experienced in machine gun springs, where the strength of the springs decreases greatly without actual failure.

"OBSTACLE-GAIN" VHF TRANSMISSION

Recent experiments with long-range VHF transmission in mountainous regions have demonstrated the possibility of utilizing knife-edge obstacles as a means for increasing the received signal energy of television, FM, and military communications. Analyses of the experimental data and interviews with scientists and engineers in the field were conducted jointly by the U. S. Army Signal Corps, the National Bureau of Standards, and the Radio Corporation of America.[1] Indications are that the disadvantages previously attributed to the transmission of very high frequencies (30 to 100 Mc) among high mountain ridges can actually become powerful aids for reducing both transmission loss and tropospheric fading. The results of these obstacle-gain experiments may have a deciding influence on the future choice of sites for

[1] The investigation of *obstacle-gain* phenomena was under the joint direction of F. H. Dickson (Office of the Chief Signal Officer, U. S. Army), J. J. Egli (Signal Corps Engineering Laboratories), J. W. Herbstreit (National Bureau of Standards), and G. S. Wickizer (RCA Laboratories).

transmitting and booster station installations. For example, in a region of the country like Colorado, it may prove more advantageous to locate FM and TV stations at lower elevations a short distance out on the plains away from the mountains rather than on the foothills right up against the very high mountains of the continental divide.

Prior to the experimental verification of the *obstacle-gain* theory, which predicts the possibility of tremendous power gains for VHF propagation over mountain obstacles, long-range communication installations were located so as to be in radio line-of-sight of each other. When possible, installations were made on the tops of mountains as a means of gaining a wider service range. The extended utilization of the very high frequencies has further intensified the quest for the best geographical site on which to establish transmitting equipment. However, the sites are usually expensive to construct and are relatively inaccessible. The *obstacle-gain* phenomenon appears to offer a solution to this problem.

Preliminary studies[2] of *obstacle gain*—which may be defined as the ratio of the received signal power with an obstacle in the path to the power received without it—showed that a considerable increase in received signal strength should result when a large knife-edge obstacle is located at the midpoint of the transmission path. Japanese scientists have made similar theoretical and experimental investigations, and their installations were observed by the joint investigating team. The group also visited engineers and scientists conducting experiments in Hawaii and Alaska.[3]

The theory upon which *obstacle-gain* transmission is based was originally proposed by Schelleng, Burrows, and Ferrell.[4] Their hypotheses, which were partially substantiated by some experimental work, stated that the transmission of very high frequencies over a knife-edge type obstacle should be considered as a four-ray combination of reflection, diffraction, and atmospheric refraction. Thus, if a transmitter and receiver are separated by a mountain, the radio waves would be received by means of the following mechanisms: (1) diffraction at the top of the obstacle; (2) reflection from the ground between the transmitter and the obstacle and then diffraction over the obstacle; (3) diffraction over the obstacle and reflection from the ground between the obstacle and the receiver; and (4) a combination of the two ground reflections with diffraction over the obstacle. The theory outlines methods by which the basic transmission loss over the path could be computed.

---

[2] Unpublished memorandum for record by H. V. Cottony, Lt. Col., Department of the Army, Office of the Chief Signal Officer (on leave from the National Bureau of Standards).

[3] The laboratories included in this investigation were the Electrical Communication Laboratory (Japanese Ministry of Communications), the Radio Research Laboratories (Japanese Ministry of Postal Services), the Mutual Telephone Company of Hawaii, and the Civil Aeronautics Administration stations in Alaska.

[4] J. C. Schelleng, C. R. Burrows, and E. B. Ferrell, "Ultra Short Wave Propagation," *Proc. IRE*, Vol. 21, p. 427 (1933).

A requirement for the use of the *obstacle-gain* method for increasing signal strength is that the height of the obstruction must be greater than the elevation of the common horizon. For example, transmission losses will be considerably reduced at 100 Mc if a knife-edge type of obstacle for a 150-mile circuit is at the mid point of the path and about 1300 feet above the surrounding terrain. Theoretically, these conditions should result in a 30-decibel decrease in transmission loss over that which would be calculated if the obstacle were not there, with an accompanying increase in received signal strength (power gain of 1000). The amount of reduction in transmission loss can be varied by different combinations of antenna heights, obstacle heights, and frequency.

Radio waves transmitted over the theoretical smooth spherical earth are considered to arrive at points within the radio horizon by virtue of a normal diffraction process and by scattering from the turbulent atmosphere. The turbulence, which is greatest near the earth's surface and decreases with increasing height into the upper atmosphere, is also considered responsible for the relatively weak and fading signals normally observed at distances well beyond the horizon.[5] The obstacle gains associated with a properly situated knife-edge ridge have been found to be large enough to reduce the transmission loss accompanying the reception of these signals beyond the horizon, thereby effectively eliminating the fading associated with the atmospheric scattering process.

A mountainous obstacle extending well above both the transmitting and receiving antennas requires the radio waves to pass through the most turbulent and disturbing regions of the atmosphere at relatively high grazing angles. With these large grazing angles, the amount of energy received from the highly turbulent regions in the screened lower portion of the atmosphere is effectively eliminated and so, in turn, is most of the tropospheric fading which normally exists on a non-obstructed path. One of the experiments designed to substantiate this theory was conducted over a 30-day period on the Alaskan circuit between Yakutat and Gustavous. The operating frequency was 38 Mc, and both the transmitting and receiving antennas were 50 feet high. During the recording period, the amount of energy delivered to the receiver was plotted against the time; the coordinates of the graph paper were also expressed in terms of transmission loss vs time. The instantaneous transmission loss for the period varied by less than $\pm$ 2 decibels from a mean value of approximately 134 db. Furthermore, the measured transmission loss was only about 7 db greater than the loss calculated from the four-ray knife-edge diffraction theory.

---

[5] J. W. Herbstreit, K. A. Norton, P. L. Rice, and G. R. Schafer, "Radiowave Scattering in Tropospheric Propagation," Institute of Radio Engineers 1953 Convention Record.

IMPROVED REFRACTOMETER

An improved refractometer for the rapid and precise measurement of index of refraction has recently been developed at the National Bureau of Standards by Oscar H. Grauer of the Bureau's glass laboratory. With the Grauer refractometer the index of refraction of specimens of glass or some other optical materials can be determined with high accuracy in a matter of minutes. Costly and time-consuming grinding and polishing operations, normally required when index-of-refraction determinations are made with other refractometers or spectrometers, are eliminated.

The instrument consists of a light source, a horizontal filament, a collimator, a diaphragm, a pair of 45-degree–90-degree cemented prisms forming a 90-degree hollow at the upper half and a parallel plate at the lower half, a filar micrometer, and a telescope. All the components are centrally aligned along a common horizontal axis.

To determine the index of refraction of a piece of glass with the Grauer refractometer, the sample is simply cut with a 90-deg. edge—no grinding or polishing is needed—and fitted into the 90-deg. hollow of the cemented prism assembly. An immersion liquid having the approximate refractive index of the sample is used as a contact liquid between the sample and the prism. The observer sees two images of the illuminated filament; the lower half of the optical system produces a direct image, while the upper half of the system gives an image that has passed through the glass sample and been refracted. Either image can be blocked out by the use of the diaphragm. The separation of the upper image from the lower image is a measure of the index of refraction of the sample, and its magnitude can be determined with the filar micrometer. Calibration of the micrometer in terms of index of refraction is a simple matter. Highly accurate readings are much more readily obtained with the filar micrometer arrangement than with the graduated goniometer circle used in other refractometers.

The glass used for the prism assembly corresponds roughly in index of refraction to the sample being measured; by substituting different prism assemblies, different ranges of index can be covered. Indices of refraction of most commercial and optical glasses lie between 1.50 and 1.70. Each prism assembly can be used satisfactorily over a range of about 0.02, so that 10 to 12 sets will cover the necessary refractive index range. With homogeneous accurately cut samples and contact liquids matching the refractive index of the sample to 0.002, an accuracy of $\pm$ 0.00002 can be obtained. Suitable certified immersion liquids are available commercially.

Because of its combination of speed and precision, the refractometer is well suited to production control and research, as well as to the general determination of refractive constants of transparent substances.

THE FRANKLIN INSTITUTE

MEDAL DAY,

Wednesday, October 21, 1953

The annual Medal Day ceremonies of The Franklin Institute were held on Wednesday, October 21, 1953. Approximately 425 persons attended the reception and dinner in Franklin Hall. Guy Marriner, Director of Music, played the National Anthem. The invocation was delivered by the Reverend Andrew Mutch, Minister Emeritus of the Bryn Mawr Presbyterian Church, Bryn Mawr, Pennsylvania. The dinner concluded with a toast to Benjamin Franklin proposed by S. Wyman Rolph, President.

Guests then adjourned to the Lecture Hall, where the President called the meeting to order at 8:35 p.m. The stated Monthly Meeting of the Institute was held in conjunction with the Medal Day exercises. The Minutes of the Stated Meeting in May were approved as published in the June issue of the JOURNAL.

Colonel Hiram B. Ely, Chairman of the Committee on Science and the Arts, then introduced the thirty-nine former Medalists who were present, and the representatives of nine former Company Medalists.

Henry B. Allen, Executive Vice-President and Secretary, was called upon to give his report on "The Institute in 1953."

Following Dr. Allen's report, the presentation ceremonies were opened by a short message from the President. The sponsor for each Medalist read the citation accompanying the award and introduced the Medalist.

At the conclusion of the awards, William Francis Gibbs, Franklin Medalist, gave a most interesting talk on the *S.S. United States* which was warmly received by the audience.

The meeting adjourned at 10:15 p.m.

The full proceedings of Medal Day will be published in the December issue of the JOURNAL.

HENRY B. ALLEN,
Secretary

PROGRAM

Reception for Medalists ..... THE HOSTESS COMMITTEE
National Anthem ..... GUY MARRINER
Invocation ..... THE REVEREND ANDREW MUTCH
Dinner ..... MEDALISTS, OFFICIALS AND GUESTS
Toast to Benjamin Franklin ..... S. WYMAN ROLPH, *President*

ADJOURNMENT TO LECTURE HALL

Greetings ..... THE PRESIDENT
Stated Meeting of the Institute ..... THE PRESIDENT PRESIDING
Introduction of Former Medalists .....
..... HIRAM B. ELY, *Chairman, The Committee on Science and Arts*
The Institute in 1953 ..... HENRY B. ALLEN, *Executive Vice-President*
Presentation of Awards ..... THE PRESIDENT
"The S. S. United States" ..... WILLIAM FRANCIS GIBBS

MEDALISTS

To be Awarded Cresson Medals (1848)

WILLIAM BLUM
Electrochemist
Washington, D. C.

GEORGE RUSSELL HARRISON
Dean, School of Science
Massachusetts Institute of Technology
Cambridge, Massachusetts

WILLIAM FREDERICK MEGGERS
Spectroscopist
Washington, D. C.

To be Awarded a Longstreth Medal (1890)

CHESTER F. CARLSON
Patent Attorney and Physicist
Fairport, New York

To be Awarded a Levy Medal (1923)

GEORGE CHENEY NEWTON, JR.
Associate Director, Servomechanisms Laboratory
Department of Electrical Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts

To be Awarded a Henderson Medal (1924)

ADOLPH MEYER
Mechanical and Electrical Engineer
Küsnacht-Zürich, Switzerland

To be Awarded Wetherill Medals (1925)

ROBERT H. DALTON
Research Chemist
Corning Glass Works
Corning, New York

S. DONALD STOOKEY
Research Chemist
Corning Glass Works
Corning, New York

To be Awarded a Brown Medal (1938)

FRANK LLOYD WRIGHT
Architect
Spring Green, Wisconsin

To be Awarded a Clamer Medal (1943)

ROBERT FRANKLIN MEHL
Dean of Graduate Studies
Director, Metals Research Laboratory
Carnegie Institute of Technology
Pittsburgh, Pennsylvania

To be Awarded a Ballantine Medal (1946)

DAVID G. C. LUCK
Member of the Technical Staff
David Sarnoff Research Center
Radio Corporation of America
Princeton, New Jersey

To be Awarded the Franklin Medal (1914)

WILLIAM FRANCIS GIBBS
Naval Architect and Marine Engineer
New York, New York

LIBRARY

The Committee on Library desires to add to the collections any technical works that members may wish to contribute. Contributions will be gratefully acknowledged and placed in the Library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open from 9 A.M. until 5 P.M. on Monday, Tuesday, Friday and Saturday; 2 P.M. until 10 P.M. on Wednesday and Thursday.

RECENT ADDITIONS

ARCHITECTURE AND BUILDING

PARKER, HARRY. Simplified Design of Roof Trusses. Ed. 3. 1953.

BIOGRAPHY

FUESS, CLAUDE MOORE. Joseph B. Eastman, Servant of the People. 1952.

CHEMISTRY AND CHEMICAL TECHNOLOGY

KENDALL, JAMES. Smith's Inorganic Chemistry. 1937.
KETELAAR, J. A. Chemical Constitution. 1953.
Organic Analysis. Vol. 1. 1953.
PLESCH, P. H., ED. Cationic Polymerisation and Related Complexes. 1953.
SISLER, HARRY H.; VANDERWERF, CALVIN A. AND DAVIDSON, ARTHUR W. College Chemistry. 1953.
STUART, H. A. Die Physik der Hochpolymeren. Vol. 2. 1953.
UMSTÄTTER, HANS. Struktur Mechanik; ein Beitrag zur Physik der Kolloide. 1948.

CIVIL ENGINEERING

Concrete Roads and Their Construction. 1920.

ELECTRICITY AND ELECTRICAL ENGINEERING

FELDTKELLER, RICHARD. Einführung in die Theorie der Hochfrequenz-Bandfilter. Ed. 4. 1953.
RAMO, SIMON AND WHINNERY, JOHN R. Fields and Waves in Modern Radio. Ed. 2. 1953.
TANG, KIWAN YAU. Alternating Current Circuits. 1940.

ENGINEERING

GRINTER, LINTON E. Engineering Mechanics. 1953.
NOVOZHILOV, V. V. Foundations of the Nonlinear Theory of Elasticity. 1953.

GENERAL

ROBERTS, KENNETH. The Seventh Sense. 1953.

GEOLOGY

HAAS, HIPPOLYT. Aus der Sturm und Drang Periode der Erde. 1892.
SHALER, NATHANIEL SOUTHGATE. Elementarbuch der Geologie für Anfänger. 1903.

MANUFACTURE

CROWN ZELLERBACH CORP. Making Paper. Ed. 3. 1953.
DUMOND, THEODORE C. Fabricated Materials and Parts. 1953.
PFANHAUSER, WILHELM. Elektroplattirung Galvanoplastik Metallpolirung. 1900.
WALTER, F. G. The Manufacture of Compressed Yeast. Ed. 2. Rev. 1953.

MATHEMATICS

BATEMAN, HARRY. Higher Transcendental Functions. Vol. 1. 1953.
COOKE, NELSON M. AND ORLEANS, JOSEPH B. Mathematics Essential to Electricity and Radio. 1943.
CURTISS, DAVID RAYMOND AND MOULTON, ELTON JAMES. Essentials of Trigonometry with Applications. 1942.
MCSHANE, EDWARD J. Order-Preserving Maps and Integration Processes. 1953.
QUENOUILLE, M. H. The Design and Analysis of Experiment. 1953.
ROMIG, HARRY G. 50–100 Binomial Tables. Ed. 2. 1953.
THOMPSON, J. E. Geometry for the Practical Man. 1934.

MECHANICAL ENGINEERING

ABC's of Diesel Engines. 1936.
DOYLE, LAWRENCE E. Metal Machining. 1953.
SCHMIDT, FRITZ. Berechnung und Gestaltung von Wellen. 1951.
SIEMON, KARL OTTO GUSTAV. Manual for the Design of Ferrous and Nonferrous Pressure Vessels and Tanks. Ed. 4. 1952.
STRENGE, HEINZ. Gleitlager ohne Buntmetall. 1951.
WALLACE, PARCY JOHN. The Technique of Design. 1952.

METALLURGY

INSTITUTE OF METALS. Properties of Metallic Surfaces. 1953.

MINING ENGINEERING

HENDERSON, P. L., ED. Brown Coal; its Mining and Utilization. 1953.

OPTICS

KLEMPERER, OTTO ERNST HEINRICH. Electron Optics. Ed. 2. 1953.

PHYSICS

BARNARD, G. P. Modern Mass Spectrometry. 1953.
DELAUNEY, CHARLES EUGENE. Traité de mécanique rationelle. Ed. 6. 1878.
GROTH, WERNER. Dynamik. Ed. 2. 1952.
HOLTZMAN, CARL. Lehrbuch der Theoretischen Mechanik. 1861.
JOHNSON, WILLIAM WOOLSEY. Theoretical Mechanics. 1901.
MACH, ERNST. Die Mechanik in Ihrer Entwickelung. Ed. 5. 1904.
MARGENAU, HENRY; WATSON, WILLIAM W. AND MONTGOMERY, CAROL G. Physics; Principles and Applications. Ed. 2. 1953.
PERRY, JOHN. Applied Mechanics. Rev. Ed. 1909.
PIOLA, DON GABRIO. Di un Principio Controverso della Meccanica di Lagrange e delle Moltiplici sue Applicazioni. 1856.
PIOLA, DON GABRIO. Sull' Applicazione de' Principj della Meccanica Analitica de Lagrange de Principali Problemi. 1825.
POORMAN, ALFRED P. Applied Mechanics. Ed. 2. 1923.
RAUSENBERGER, OTTO. Lehrbuch der Analytischen Mechanik. Vol. 1–2. 1888.
REYNOLDS, JOSEPH B. Analytic Mechanics. 1929.
ROHAULT, JACQUES. A Treatise of Mechaniks. 1716.
ROUSE, HUNTER AND HOWE, JOSEPH. Basic Mechanics of Fluids. 1953.
SMITH, D. M. Visual Lines for Spectrographic Analysis. Ed. 2. Rev. 1952.
SOMOFF, J. Theoretische Mechanik. Vol. 1–2. 1878–1879.
VOIGHT, WOLDEMAR. Elementare Mechanik. Ed. 2. 1901.
WILSON, ROBERT F. Color and Light at Work. 1953.

RAILROADS

BRUCE, ALFRED W. The Steam Locomotive in America. 1952.
HAY, WILLIAM. Railroad Engineering. Vol. 1. 1953.

SCIENCE

BAWDEN, ARTHUR TALBOT. Man's Physical Universe. 1937.
MENER, ARNOLD. Das Wunderbuch der Technik. 1927.
TRUE, WEBSTER PRENTISS, ED. Panorama of Science, 1952. 1952.

JOURNAL OF THE FRANKLIN INSTITUTE

The following papers will appear in this JOURNAL within the next few months:

MOON, PARRY AND DOMINA EBERLE SPENCER: The Meaning of the Vector Laplacian.
PISTER, KARL S.: The Airy Stress Function in Curvilinear Coordinates with Application to the Uniform Flexure of a Naturally Curved Spiral Beam.
SEAL, PHILIP M.: Analysis of Network Response to Periodic Laws.
BULAND, R. N.: Analysis of Nonlinear Servos by Phase-Plane-Delta Method.
TOMOVICH, RAJKO: A Versatile Electronic Function Generator.
POWLEY, HOMER S.: Rapid Estimation Method for Long-Pointed Projectile Trajectories.

MEMBERSHIP

ACTIVE MEMBERS ELECTED AT THE MEETING OF THE BOARD OF MANAGERS, OCTOBER 21, 1953

ACTIVE

Francis J. Berger
Albert K. A. Christian
Luke W. Corbett
John W. Cornell, Jr.
Roy B. David
Albert J. Ferkel
Mrs. David Gwinn
Irwin W. Hally
F. Norton Landon
James Matarese, Jr.
John W. Merriam
C. Anthony Moore
John T. Moynihan
Fred G. Schutz
Charles P. Williams
George W. Ziegler, Jr., Ph.D.

ACTIVE NON-RESIDENT

John J. Burns
Henry E. Warren

NECROLOGY

George H. Bauder '51
Joseph T. Fewkes '42
Alfred Gordon, M.D. '44
William Gravell '39
Harold R. Keeler, M.D. '44
William Kurtz Myers '50
William C. Shank '49
George d'Utassy '19

NOTES FROM THE FRANKLIN INSTITUTE MUSEUM

A. C. CARLTON, EXECUTIVE DIRECTOR

PAPERMAKING

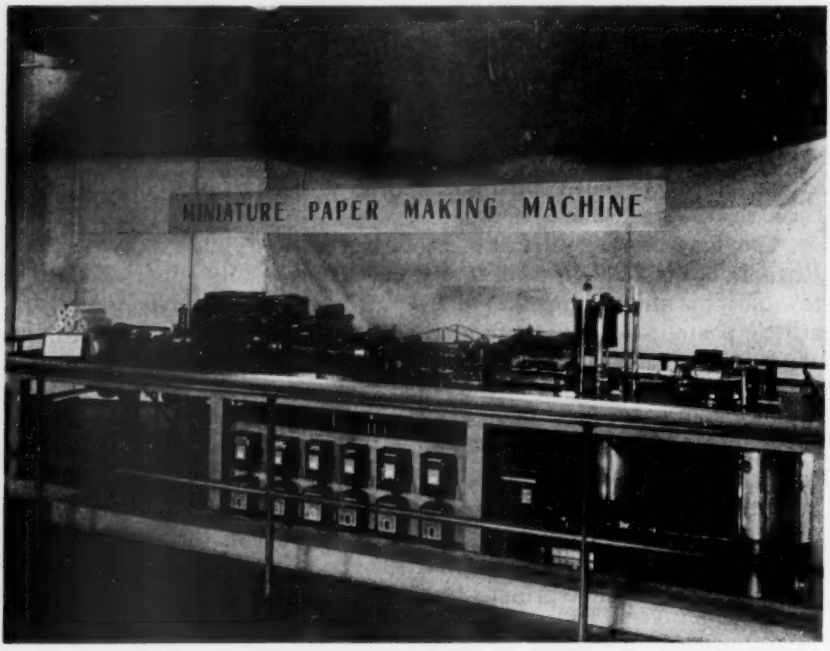
By the time of the Middle Ages the work of copying books by hand was well established. Nearly all the scribes were monks and, since they were principally concerned with eternity and preparing people for it, most of the books related to religion. Some way of providing books in greater quantity and less time had to be found to fill the void on this side of eternity. Paper and printing were necessary. Once these were brought together they contributed to the enormous spread of knowledge through books and newspapers.

The first paper mill in this country was established by William Rittenhouse in 1690 on what is now called Paper Mill Run, in Germantown. This mill produced writing, printing, brown and blue paper, and a little pasteboard. The production was so small that a printer operating a hand press could consume all the paper that three men could make in its one vat.

The early mills used linen rags as their raw material. As the relatively small population of the country was widely scattered, the collection of rags was no easy matter. Moreover, the rag bag had not been invented; needs were so great that people did not discard their clothes until they were beyond repair. This restriction in the supply of raw materials often led newspaper publishers to dire straits in order to obtain the desired newsprint. Improvements in printing machinery had far outrun the slow progress made in papermaking, and printers were almost driven distracted in their efforts to find paper so that their workmen could be kept employed.

Early in the eighteenth century the French scientist Reaumur had learned that the American wasp's nest was constructed of the finest paper. He suggested that a study of the wasp's digestive processes might reveal how cellulose could be converted into unlimited supplies of paper for man's use. This suggestion went unheeded except by a few men who made tentative efforts to apply their chemical knowledge to the subject, but none was able to secure production of paper from cellulose, the principal part of the solid framework of all leafy plants, in commercial quantity. It was not until the middle of the nineteenth century that Hugh Burgess, Benjamin Tilghman, Friedrich Keller, and others succeeded in making good pulps by boiling wood in caustic soda or sulfuric acid, and started scientific research on its long path to improve paper manufacture.

Fortunately, excellent machines were available for the enormous amount of paper which could now be produced at low cost to meet the increased needs. One of these machines, the Foudrinier, can be seen at work in the Museum at weekends. The normal Foudrinier is much too large for a museum exhibit, but a small scale model, so perfect in all its parts that it makes real paper, answers the requirements. The entire process from pulp to finished paper can be witnessed in operation.



It is not generally known that this accurate scale model serves a useful purpose apart from entertaining visitors. The Franklin Institute has always exercised the keenest interest in promoting industrial experiment and, in pursuit of this policy the model Foudrinier machine can be used at very low cost by those who wish to make experiments in papermaking. Some of the strangest pulps have passed over its web, embodying glass, rubber, magnesia and a variety of other unlikely substances which, nevertheless, have turned out highly satisfactory papers for special purposes.

NOTES FROM THE FRANKLIN INSTITUTE LABORATORIES
FOR RESEARCH AND DEVELOPMENT

NICOL H. SMITH, DIRECTOR

AN 18-CHANNEL SPECTROMETER*

BY

LOUIS S. HERCZEG

An eighteen-channel spectrometer has been designed for use in the near infrared region, but as indicated in the following notes the ease with which the design can be modified makes it extremely versatile. In its present form, the instrument can detect and record spectral phenomena at eighteen points in the region between one and 3.6 micron wave length. The range is limited by the sensitivity of the Ektron cells. This can be increased to 4.3 micron by operating the detectors at $-40°$ C.

The optical part of this system consists of: (1) An off-axis collimating mirror; (2) A LiF prism and a plane mirror used in a Wadsworth arrangement, and (3) A focusing mirror. This system is very flexible and can be changed to meet various specifications. If greater resolution and dispersion are demanded, the optics can be changed to a double Wadsworth system. Different prisms can be used depending on the wavelength ranges to be investigated.

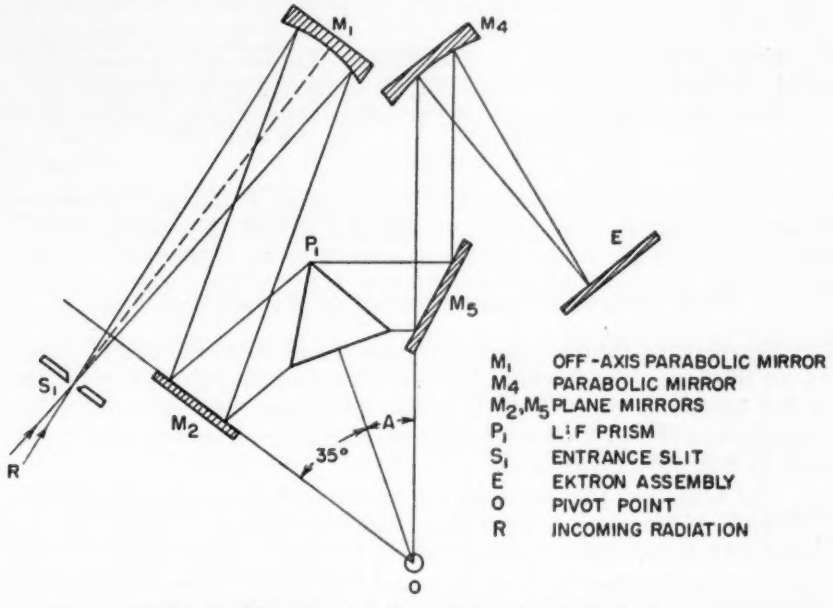


FIG. 1. Optical system of the 18-channel spectrometer.

* Development of this instrument was supported by Signal Corps Engineering Laboratories, Fort Monmouth, N. J.

The detectors, amplifiers, and recording system were chosen so that pulse phenomena ranging from 4 to 150 milliseconds could be accurately recorded. This spectrometer can also be used to investigate (1) pulsating signals that vary from .06 cycle/sec. up to a maximum rate of 600 cycles/sec., and (2) non-varying radiation (by chopping the signal as it enters the spectrometer). The detectors consist of 18 lead sulfide strips chemically deposited on a single glass plate. These elements (Ektron cells) are $\frac{1}{2}$ mm. wide and they are spaced $\frac{1}{4}$ mm. apart. This assembly is located in the focal plane of the instrument with the minimum deviation wavelength falling on a center element. The widest spectral region intercepted at any setting of the spectrometer is roughly 1.7 microns. The wavelength band falling on each detector is nearly .06 micron.

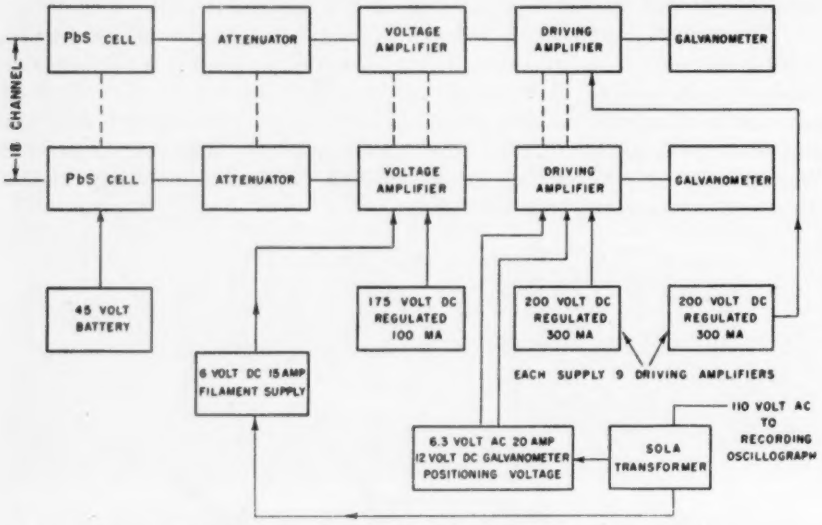


FIG. 2. Detecting and recording system of the 18-channel spectrometer.

Signals from the Ektrons are amplified and then recorded by means of an 18-channel oscillograph. For our application galvanometers with a flat frequency range from 0 to 500 cycles/sec. are used, but galvanometers can be used whose frequency ranges vary from 0 to 10.5 cycles/sec. to 0 to 3000 cycles/sec.

The amplifiers that increase the signals from the cells sufficiently to drive the galvanometer have been designed so that 10 micro volts of noise will deflect the recording traces 1/16 in. The limiting low-frequency time constant of these units is 2.5 seconds. This corresponds to a low frequency 3 db. point of .064 cycle/sec. Attenuators are used in conjunction with these amplifiers so that the instrument can measure signals that range from 10 micro volts to 2 volts.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

ELLICE McDONALD, DIRECTOR

PHOSPHATASE ACTIVITY IN RAT LIVER IN RELATION TO CELLS AND MITOCHONDRIA

BY

J. O. ELY AND M. H. ROSS

The phosphatase activity of tissues usually has been expressed per unit weight of tissue or per unit of nitrogen in aqueous extracts (1). Results so expressed may bear little relation to the enzyme activity of the individual cell since the cell population per unit volume varies among tissues, and in some tissues may change radically with the nutritional condition of the organism (2).

It was reported previously that, per unit weight of tissue, the alkaline phosphatase activity in the livers of rats fed a protein-free diet was much greater (1) and that the acid phosphatase activity was no greater than the activity in the livers of rats fed a standard laboratory stock diet. In those experiments no consideration was given to differences in cellular content of the tissues. Further investigation has shown that results, when related to the number of cells in the tissue, differ radically from those based on tissue weight.

Several enzymes and enzyme systems have been found to be associated predominantly or entirely with the mitochondria (3–12). Since acid phosphatase apparently is one of those enzymes (3, 8) the mitochondrial content of the liver cells of rats comparable to those used for the enzyme studies was determined in order to detect any correlation that might exist between enzyme activity and mitochondrial content.

EXPERIMENTAL

Rats of the Wistar strain 160–170 gm. in weight were maintained for 30 days on a Fox Food Blox diet, an Allied Mills product, containing 26 per cent protein, or on a protein-free diet (dextrose, 89 per cent; corn oil, 5 per cent; salt mixture, 4 per cent; rice bran extract, Vitab, 2 per cent; riboflavin, 0.002 per cent.)

After decapitation of the animals, pieces of livers were homogenized in distilled water in a Waring Blendor at low speed for one minute. Alkaline phosphatase activity measurements were made on the homogenates at pH 9.1, 37° C., with sodium-β-glycerophosphate as the substrate. Acid phosphatase activity was determined by the same method at pH 5.0.

The number of nuclei per gram of tissue was determined by counting in a hemacytometer the number in suitably diluted homogenates made in 5 per cent cold citric acid.

Mitochondria were counted in homogenates of the liver tissue in 0.25 M sucrose solution by the method described by Shelton, Schneider and Striebich (13).

Per gram of liver the alkaline phosphatase activity and the number of nuclei were twice as great in the animals fed the protein-free diet as in the animals fed the Fox Food Blox diet: therefore, if the number of nuclei be considered an index of the number of cells, the activity per cell was the same (Table I).

TABLE I.—*Alkaline and Acid Phosphatase Activity of Rat Liver.*

		No. of Rats F.F.B. Diet	No. of Rats P-F Diet	Fox Food Blox Diet	Protein-Free Diet
Mg. P liberated/hr./gm. tissue wet wt.	Alkaline	35	35	1.08 ± 0.02*	2.22 ± 0.25
	Acid			14.57 ± 0.12	14.63 ± 0.45
No. of nuclei/gm. of tissue ($\times 10^{-8}$)		5	5	1.94 ± 0.20	3.93 ± 0.24
Mg. P liberated/hr./1 $\times 10^{8}$ nuclei	Alkaline			0.56	0.56
	Acid			7.51	3.72
No. of mitochondria/gm. of liver ($\times 10^{-10}$)		5	5	11.9 ± 1.17	5.5 ± 1.46
No. of mitochondria/nucleus		5	5	623 ± 87	160 ± 39
Mg. P liberated/hr./1 $\times 10^{10}$ mitochondria	Alkaline			0.091	0.404
	Acid			1.22	2.66

* Standard error of the mean.

Although the number of cells per gram of liver was twice as great in the protein-free diet group as in the Fox Food Blox diet group the number of mitochondria per gram was only one-half as great; per cell the number of mitochondria was thus approximately one-fourth as great (160, protein-free; 623, Fox Food Blox). The alklaline phosphatase activity, calculated on the basis of the mitochondrion, was approximately four times as great in the protein-free diet group as in the Fox Food Blox diet group (Table I).

The acid phosphatase activity per gram of tissue was equal in the two groups although the livers of the protein-free diet group contained twice as many cells per gram as were present in the Fox Food Blox diet group; per cell therefore, the enzyme activity was only half as great in the livers of the protein-free diet group as in the other group. Since the acid phosphatase activity per cell was one-half as great in the protein-free diet fed group and the number of mitochondria per cell one-fourth as great, the activity per mitochondrion was approximately twice as great in the livers of the protein-free diet group as in the livers of the Fox Food Blox diet group (Table I).

DISCUSSION

The livers are rapidly depleted of protein when rats are fasted or are fed a protein-free diet (1). The data show that despite loss of proteins the alkaline phosphatase activity of the average cell did not change although the number of cells per gram doubled. This doubling of the number of cells without reduction of the phosphatase activity per cell, doubled the activity per unit volume or per unit weight of tissue.

Acid phosphatase activity, in contrast to alkaline phosphatase activity, remained unchanged per gram of liver as previously reported (1) but decreased per cell when the protein-free diet was fed. The protein lost either depleted the cell of this enzyme or decreased the activity in some other manner. These results emphasize the importance of expressing analytical data on a cell basis as suggested by Ultmann (14).

The numbers of mitochondria per gram of liver and per nucleus are in fairly close agreement with the findings of Striebich, Shelton and Schneider (15) for rats fed similar diets.

The greater activity of both acid and alkaline phosphatase per mitochondrion in the protein-depleted livers may be interpreted as indicative of (*a*) no close association of these enzymes with the mitochondria, or (*b*) the existence of different classes of mitochondria as suggested by Schneider and Potter (10) and a decrease in other classes than those with which these enzymes are associated. The latter interpretation includes the assumption of an increase either in the number of the mitochondria with which these enzymes are associated or in the enzyme content of such mitochondria. Until more information is available a choice between these interpretations cannot be made.

SUMMARY

The alkaline phosphatase activity *per cell* was not altered by protein depletion of the livers of rats caused by feeding a protein-free diet but per gram of tissue the activity and the number of cells were doubled. The acid phosphatase activity in the livers of rats fed the protein-free diet although unchanged per gram was only 50 per cent as great per cell as in the livers of rats fed the Fox Food Blox diet.

Protein depletion decreased the number of mitochondria per cell, but greatly increased the alkaline and acid phosphatase activity per mitochondrion.

REFERENCES

(1) M. H. Ross, J. O. Ely and J. Archer, Jour. Franklin Inst., **255**, 87 (1953).
(2) J. O. Ely and M. H. Ross, Jour. Franklin Inst., **254**, 189 (1952).
(3) J. Berthet, L. Berthet, F. Appelmans and C. de Duve, *Biochem. J.*, **50**, 182 (1951).
(4) G. C. Cotzias and V. P. Dole, *Proc. Soc. Exptl. Biol. Med.*, **78**, 157 (1951).
(5) J. W. Harman, *Exptl. Cell Research*, **1**, 382 (1950).
(6) G. H. Hogeboom, W. C. Schneider and G. E. Pallade, *J. Biol. Chem.*, **172**, 619 (1948).
(7) E. P. Kennedy and A. L. Lehninger, *J. Biol. Chem.*, **179**, 957 (1949).
(8) G. E. Palade, *Arch. Biochem.*, **30**, 144 (1951).
(9) W. C. Schneider, *J. Biol. Chem.*, **176**, 259 (1948).
(10) W. C. Schneider and V. R. Potter, *J. Biol. Chem.*, **177**, 893 (1949).
(11) W. C. Schneider and G. H. Hogeboom, *J. Biol. Chem.*, **198**, 155 (1952).
(12) P. Siekevitz and V. R. Potter, *J. Biol. Chem.*, **200**, 187 (1953).
(13) E. Shelton, W. C. Schneider and M. J. Striebich, *Exptl. Cell. Research*, **4**, 32 (1953).
(14) J. E. Ultmann, E. Hirschberg and A. Gellhorn, *Cancer Research*, **13**, 14 (1953).
(15) M. J. Striebich, E. Shelton and W. C. Schneider, *Cancer Research*, **13**, 279 (1953).

BOOK REVIEWS

ADVANCES IN APPLIED MECHANICS, VOLUME III, edited by Richard von Mises and Theodore von Karman. 324 pages, diagrams, 16 × 24 cm. New York, Academic Press, Inc., 1953. Price, $9.00.

As in previous volumes already published under the same title, Volume III deals with various subjects of present-day research in applied mechanics. It is a compilation of seven different papers covering various topics which may be classed under the general heading of applied mechanics. Most of the papers tend toward fluid flow and associated phenomena, but included also are papers on plasticity and non-autonomous systems. This non-homogeneity, if not intentional, may be due to the last minute withdrawal of a key paper and the necessity of substituting other work in its place.

Boundary layer problems are discussed in one paper in general, and several applications of the theory are presented. This is followed by an article on one-dimensional isentropic fluid flow in which emphasis is placed upon continuous motion. The paper summarizes the progress that has been made by recent analytical approaches to the problem.

Another paper deals with one aspect of turbulent phenomena, turbulent diffusion. This has application in many fields, particularly fluid dynamics, chemical engineering, meteorology and heat transfer. A discussion of the statistical description of turbulence is included to show the relation between turbulent diffusion and the general theory of turbulence. The fundamental equation of turbulent diffusion is derived and is applied to a field of homogeneous and isotropic turbulence.

Next, a paper is presented covering the aerodynamics of blasts. Here analytical methods are presented to show the influence of various boundaries on the form and pressure field of passing blasts.

Another paper treats certain shock occurrences which have been shown by experiment to exist in supersonic regions embedded in subsonic flow. The authors first give a mathematical discussion of the phenomena and then bring out the physical significance.

A short discussion of vortex systems in wakes is presented with ample reference to original works which have dealt with the general problem.

The longest paper in the book deals with some recent aspects of the mathematical theory of plasticity. It covers a definition and derivation of a general plane problem, and the discussion of specific problems. Many references are given in the text and bibliography.

The book is concluded with a paper on non-autonomous systems. These are systems described by a non-autonomous equation of the form

$$\ddot{x} = F(x, \dot{x}, t).$$

The book is intended specifically for the reader with a wide background in applied mechanics. Since many of the papers are of a summary nature, previous knowledge of the works referenced are needed to follow the text clearly. There are, however, ample reference and bibliography for those who would wish to explore these topics in further detail.

R. H. MARVIN

THE STABILITY OF ROTATING LIQUID MASSES, by R. A. Lyttleton. 150 pages, diagrams, 19 × 27 cm. New York, Cambridge University Press, 1953. Price, $6.50.

The book covers those parts of the theory of the stability of rotating gravitating liquids that seem to be of importance in determining the evolution of such systems. The problem is of considerable interest from a cosmogonical standpoint, as it constitutes the only source of theoretical information on the question of how an isolated unstable rotating mass will develop. The author reaches important conclusions contrary to previous ones, which are still largely current among astronomers, that the dynamical evidence is entirely adverse to the so-called fission process of formation of binary systems. The most important mathematical result is that the pear-shaped figure is quite certainly secularly unstable. This is based upon results of Liaponoff, Jeans and even Darvin's original investigation. This means

that the pear-shaped form itself never comes into existence. According to the fission theory, the origin of binary stars is regarded as due to the break-up of a single mass by its rotation.

The author proves on purely dynamical grounds that the process of instability cannot result in the formation of a double system consisting of two comparable masses moving in close orbital motion about each other. He argues that after the process of break-up the portions must be of considerably different sizes, and the smaller one must escape entirely from the gravitational field of the larger one. It is suggested that the great planets represent the surviving main portions of such rotational disruptions of a number of larger primitive planets. The author's hypothesis is as follows: Considering the disruption itself in more detail, it is not to be expected that this would take place simply as a clear division into two separate parts. It seems likely that a stream of material would form stretched between the masses and would have a velocity between those of the main masses. Such a stream would not be a stable arrangement, and as the main masses separate, would break up into small masses. The ones nearer the ends might have insufficient speeds to escape the adjacent main mass, but the general rotation associated with the original mass would be maintained and endow each of these small masses with orbital angular momentum about it. In this way, the larger residual portion might come to possess a system of small satellite masses moving about it at distances comparable with the size of the body itself, and in the same general direction as that determined by the rotation of the main body.

The sequence of chapters is as follows: I. Introduction; II. Stability; III. The spherical form; IV. The spheroidal and ellipsoidal forms; V. Ellipsoidal harmonic analysis; VI. Properties of Lamé functions; VII. The secular stability of the MacLaurin spheroids; VIII. The secular stability of Jacobi ellipsoids; IX. The ordinary stability of the Jacobi ellipsoids; X. Cosmogonical implications; References. The Cambridge University Press preserved its tradition in the excellent printing of the book, which is a very interesting contribution to the theory of cosmogonical phenomena.

M. Z. v. KRZYWOBLOCKI

MATHEMATICAL PHYSICS, by Donald H. Menzel. 412 pages, diagrams, 16 × 24 cm. New York, Prentice-Hall, Inc., 1953. Price, $8.50.

A student intending to make physics his major subject usually begins with a general physics course in his undergraduate years. He then proceeds to higher courses in the various fields into which physics is conventionally divided. The content and scope of the texts he uses, no matter who their authors, are usually well defined by the titles of the texts. Early in his graduate work, he normally takes an advanced course in general physics and meets a text called "Theoretical Physics," or even "Mathematics for Physicists." The content of the books written for these courses is much less predictable from their titles. They may be almost wholly expository, using mathematics as a tool but placing no special emphasis on the techniques; they may be organized in alternate chapters of mathematical methods and physical applications; or, at the extreme, they may be almost wholly mathematical, with the physics entering only as illustrative examples and problems for the student. All in all, they strongly reflect the author's special interests, and the teaching demands his courses have placed upon him.

Dr. Menzel's book does not fit in a clear-cut way into one of the above categories, but seems to overlap the latter two. It gives the impression of being somewhat uneven in its demands upon the student, perhaps because it has been designed, according to the preface, for use in junior, senior, or graduate courses. The organization is in parts, of which there are five, rather than chapters.

Part I is devoted to units and dimensions. The treatment is more detailed than normal for an advanced text, and includes a section on dimensional analysis, and an extensive table of physical constants from Du Mond and Cohen. The reason for the inclusion of this table is puzzling, since the majority of constants listed are atomic in nature and find no application in the present volume.

Some of the definitions in this part carry a stamp of individuality, such as that defining the "moment of an infinitesimal body with respect to a plane . . .," or that which states "Electric potential or electromotive force is the ratio of the work done in an electric circuit

per unit of electricity operative." This seems to leave no room for the concept of an electrical potential independent of a physical circuit. Other definitions are ambiguous, or incorrect. For example: "Frequency is the number of times per unit of time that a given physical quantity assumes the same value." This is, of course, just twice the frequency as customarily defined and as actually used in the book. Or we find "Moment of momentum of an infinitesimal body with respect to a point is the product of the momentum of the body by its distance from the point." And "Torque moment of force or centrifugal couple, is the product of a force by a length." These are only a few of the definitions which are faulty. Some of the trouble seems to stem from the failure to introduce vector concepts clearly at the initiation of the volume. Although vector notation is used in connection with some of the definitions, the notation is not defined until Part II. Perhaps the author intended the definitions in Part I to have only dimensional significance; if so, he has not made that intent clear. And how can this explain the statement "Being a ratio, the specific heat is dimensionless."?

Part II treats Classical Mechanics and Dynamics. The first nineteen sections are essentially elementary potential theory and spherical harmonics. Harmonic functions are defined as solutions of Laplace's equation, but are not introduced by the solution of that equation, but by the binomial expansion of the denominator in the potential integral. There is no direct demonstration that the functions developed *are* solutions of Laplace's equation. The next seven sections introduce vector analysis, illustrated by the two-body problem. Then follows an excellent set of sections on Dyadics, Matrices, and Tensors, which is wholly mathematical, with no illustrative applications. A return is then made to vector operations to introduce Stokes' Theorem and general orthogonal curvilinear coordinates. This leads to a discussion of hydrodynamics, in which we must be careful to note that "external force" is sometimes really force per unit mass.

The foregoing material has been based on the Newtonian formulation of mechanics. The last five sections are devoted to a brief development of the Lagrangian and Hamiltonian formulations, including Hamilton-Jacobi theory, Poisson brackets and contact transformations. The material is essentially unillustrated.

It should be noted that no treatment of rigid body rotations is given, nor is there any discussion of elastic deformation.

Part III is entitled "Waves and Vibrations," and serves to present Fourier methods and eigenvalue concepts. A short expository section discusses the significance of wave functions in quantum mechanics, followed by a section on the vibrating string with complex wave velocity, which leads to the Hermite polynomials. The part on waves and vibrations is well done.

Part IV treats classical electromagnetic theory. Throughout this part all important equations are given in duplicate, first in Gaussian units, second using the mks system. The treatment is conventional, beginning with Coulomb's Law for electric charges and for magnetic poles, proceeding to the electric and magnetic potentials. The emphasis is placed on the field intensity vectors, and the introduction of the magnetic induction and the electric displacement is delayed to sections 10 and 14, respectively. Following Maxwell's equations the polarization and magnetization are defined.

The book then takes up radiation theory and treats the force on a charged particle, field energy, Poynting vector, plane wave, radiation pressure, reflection and refraction, absorption in a charged medium, radiation from an accelerated charge and from a linear oscillator, etc. Part IV concludes with the Hamiltonian for the electromagnetic field.

Part V is in two sections the first treating the special theory of relativity, the second discussing the general theory. Use is made of the tensor notation developed earlier in Part II. This concludes the text.

It should be noted that thermodynamics and statistical mechanics are omitted. There are 193 problems well varied in difficulty. There is no bibliography, nor are there any recommended references. ALAN C. BYERS

ENGINEERING MECHANICS, by Linton E. Grinter. 408 pages, diagrams, 16 × 24 cm. New York, The Macmillan Company, 1953. Price, $5.75.

One of the first steps to be made in the solution of problems in mechanics is to make

a sketch of the problem and to show all the forces involved. When an engineer has done this, his problem is well on the way to solution. Such an approach makes the difficult problem easy, and the easy, easier. It is therefore a pleasure to find this bit of advice among such others as how to study, how to make an orderly calculation, the necessity of checking all computations, and the need to question assumptions always, in a new book on mechanics. The author has considered this advice of such importance that he has devoted a special introductory chapter to it.

Written by a former professor of mechanics at the Illinois Institute of Technology, *Engineering Mechanics* reflects the high engineering standard of the school in its sound treatment and presentation of the fundamentals of statics and dynamics. Dr. Grinter, now Dean of the Graduate School and Director of Research at the University of Florida, maintains a fine balance between theory and practice in his book. Having taught for many years, he knows the value of practical problems in illustrating and explaining theoretical concepts.

Distinguished by its clear treatment of content rather than by its contents, *Engineering Mechanics* contains the usual material in an introductory book on mechanics. Consequently, there are chapters on statics (components, resultants and equilibrium of forces), structural analysis, friction, moments of inertia, kinematics; on dynamics (mass-acceleration, work and energy, impulse and momentum), vibration and balancing of structures and machines, and the principle of virtual work. The book is further characterized by many line drawings and illustrations.

E. W. HAMMER

METAL MACHINING, by Lawrence E. Doyle. 511 pages, illustrations, 15 × 22 cm. New York, Prentice-Hall, Inc., 1953. Price, $10.00.

Metal Machining brings to our attention important facts about the metal machining processes and the opportunities for improving efficiency through process planning. Fundamentals are covered in chapters on Tolerances, Measurements and Gauging, and on Cutting Tools. All important machine operations are explained and appropriate equipment for doing each is described. The book progresses from simple lathe operations to complex machines for gear cutting and from methods suitable for making one piece to those suitable for economically producing thousands.

Often several methods of production are possible. It is here that the elements of process planning are set forth. This involves an appraisal of many factors, a few of which are machines, materials, feeds, speeds and operators. From these, the most desirable method for a particular situation is developed. One chapter on process planning highlights the essentials, but frequent emphasis on the elements important to process planning is made throughout the book. Each chapter concludes with questions and references which will facilitate study.

The author successfully gathers together the many details and techniques of metal machining, combining these with the broad concepts of process planning into a very readable book useful to the engineer as well as the student.

C. HESELWOOD

AUTOMATIC CONTROL OF HEATING AND AIR CONDITIONING, by John E. Haines. 370 pages, diagrams, 16 × 24 cm., New York, McGraw-Hill Book Co., Inc., 1953. Price, $6.75.

In 1948, the Minneapolis-Honeywell Regulator Company published an excellent 260 page booklet entitled "Control Manual for Heating, Ventilating and Air Conditioning." This booklet summarized their equipment catalogue and gave the theory and design information useful to the practicing engineer. It is still used by many as a reference in this specialized field.

Mr. Haines, Vice President of Minneapolis-Honeywell Regulator Company, drew heavily on this tried and tested booklet in preparing his manuscript. The sections on control circuits and on the control of commercial central-fan heating and cooling systems were excellent and have been changed little. Although most of the illustrations are of M-H equipment, no mention of the name of the manufacturer is displayed.

This is the first textbook of its kind in the field of automatic control for air conditioning, and it is backed up by a wealth of experience. Mr. Haines opens the textbook with definitions of the terms to be used and the fundamentals of measurement and control. He then illustrates and explains typical electric

and pneumatic control circuits and control units. The author goes into the greatest detail in the consideration of the heating phase of air conditioning. Separate chapters are devoted to the control of domestic heating, commercial heating, and radiant-panel heating. Other chapters are devoted to the control of ventilation, cooking, humidification, and refrigeration.

Automatic Control of Heating and Air Conditioning is intended to be an elementary textbook, not an advanced technical treatise. It is directed neither at the service man nor the mathematician. Instrument manufacturers have booklets for the service men, while the publisher carries a series of books entitled "Instrument Engineering" which considers the operation of instruments from the mathematical point of view. Mr. Haines directed this book toward the air conditioning student and the application engineer. All methods of control which are generally used are illustrated and described. Their advantages and limitations are discussed. The illustrations are excellent, and these alone are worth the cost of the book. Several new and accurate sensing devices and circuits have recently been developed and placed on the market. They were omitted from this book possibly because the author wished to be conservative.

Because this is an introductory textbook in an important field not previously covered, and because it is well written and well illustrated, the reviewer wishes to recommend it as an essential textbook for the beginner, and as an excellent reference book for the application engineer in the field of automatic controls.

A. D. HAY

LUMINESCENCE AND THE SCINTILLATION COUNTER, by S. C. Curran. 219 pages, diagrams, 15 × 22 cm. New York, Academic Press, Inc.; London, Butterworth's Scientific Publications; 1953. Price, $5.80.

The scintillations produced in a zinc sulfide screen when struck by alpha particles or protons were widely used in the early studies of nuclear phenomena. The method fell into disuse because the scintillations had to be observed by eye and counted manually. About a decade ago the method gained new prominence when automatic counting of the scintillations by photomultipliers and electronic counters was introduced. This book summarizes this decade of work.

This modern scintillation counter consists of a suitable luminescent material to produce a flash of light (usually visible or near ultraviolet) when struck by a particle or quantum of electromagnetic radiation, a photomultiplier to detect the flashes, and suitable circuits for counting and measuring the pulses produced by the photomultiplier.

Two introductory chapters outline the counter and those aspects of the interaction between radiation and matter which are of importance to this subject. The remainder of the book is largely concerned with discussions of the three components of the counter mentioned above. A fairly complete description of photomultipliers with particular emphasis on important operating characteristics is given

After an introduction to the theory of luminescence the preparation, properties, and important operating characteristics of useful luminescent materials are described. As in the discussion of photomultipliers the emphasis here is on practical aspects of scintillators as used in counters. Final chapters deal with applications of scintillation counters to the study of radiation of various types and the circuits used for recording the pulses.

The book is well illustrated and contains both author and subject indexes. It thus provides a very good guide to the use of scintillation counters. E. R. STEPHENS

MEASUREMENT TECHNIQUES IN MECHANICAL ENGINEERING, by R. J. Sweeney. 309 pages, diagrams, 16 × 24 cm. New York, John Wiley & Sons, Inc., 1953. Price, $5.50.

Devices and techniques to measure various mechanical properties are generally described in books on the various fields of mechanical engineering. Devices to measure electricity are found in books on electricity; those to measure temperature, in books on heat; and so on. Special papers are often devoted to specific measuring devices. It is seldom, if ever, that one finds a book concerned solely with all types of measuring devices and techniques in the field of mechanical engineering, exclusive of those for materials testing and experimental stress analysis. Such a book however, is *Measurement Techniques in Me-*

chanical Engineering by R. J. Sweeney, a consulting engineer with considerable teaching and industrial experience. By providing a description of such a wide variety of measuring instruments together with their usage under one cover, this book should be of much value to the engineering profession.

Beginning his book with a discussion of measurement, including instrument factors, installation errors, selection of instruments and instrument control systems, Mr. Sweeney proceeds to discuss mensuration and the various instruments to record mass, time and speed, and electricity. Dynamometers, various pressure gages, instruments to determine temperature, instruments to measure fluid flow are next described. The book concludes with a discussion of steam and fuel colorimeters, methods of chemical analysis of gases, water and coal and a final chapter on automatic controls. E. W. HAMMER

DIELECTRIC AERIALS, by D. G. Kiely. 132 pages, 11 × 17 cm. Methuen's Monographs on Physical Subjects. New York, John Wiley & Sons, Inc.; London, Methuen & Co., Ltd.; 1953. Price, $2.00.

During and immediately after World War II there was carried out intensive theoretical and experimental research in the use of hollow metal waveguides. But little attention was given, until recently, to the possible use of dielectric rods, hollow tubes and horns as energy carriers and radiators. One reason for this lag may be the relative complexity of problems pertaining to dielectric radiators.

The field is too new to justify a textbook on the subject. This monograph collects the scattered literature, presents a general review of existing theoretical and experimental work concerned with radiation pattern characteristics, derives mathematical expressions for them, and points out directions in which additional theoretical and experimental work should be done. The volume serves its purpose well as a critical review of the field allowing the reader to obtain a broad picture of present developments with comparatively little expenditure of effort.

The subject matter is presented in four chapters concerned with propagation along a dielectric rod, and the properties of rod, tube and horn radiators. The first of these chapters is, of course, basic. Starting with Maxwell's equations, the E and H field distributions are developed for circular and non-circular symmetric waves. Once the field configuration is known, the rod can be excited. It is fortunate indeed that the required configuration is similar to that present in a hollow metal waveguide. This allows the dielectric rod to be excited merely by inserting it into the end of a hollow metal guide.

At the present time no wholly satisfactory theory has been developed to analyze the radiation pattern characteristics of dielectric antennas in such a way as to explain fully the experimentally observed phenomena wherein the main lobe of the pattern is directed along the rod and its directivity is proportional to the length of the rod. Three theoretical methods are reviewed and compared to explain the observed results: the first uses Huygen's principle and ray theory; the second uses a wave-length lens approach; and the third, and most advanced, method uses the Schelkunoff equivalence principles.

The chapters devoted to tubes and horns review derivations of field configurations and their dependencies on parameters of the problem.

Physicists and engineers who are concerned with the design of centimetric radiators would do well to read this monograph. Some of the design data may be directly applicable to their work. The new problems pointed out by the author should no doubt spur additional research in this field. S. CHARP

THE FURANS, by A. P. Dunlop and F. N. Peters. ACS Monograph No. 119. 867 pages, diagrams, 16 × 24 cm. New York, Reinhold Publishing Co., 1953. Price, $18.00.

About thirty years ago, when furfural was first obtained from oat hulls, a new field was opened in organic chemistry. As more and more research was carried on, there was much interest expressed by industry. Keeping pace with the growth of research in furan compounds was the literature. As a result, the need for a summarization of the research and of the industrial uses became urgent and important. Two men who had done so much of the early work with furfural and who have concerned themselves with the theoretical aspects and commercial problems are Dr. F. N. Peters and Mr. A. P. Dunlop. They

have had an active part in the development of this field and have contributed much of the literature. It naturally follows that they were well qualified to undertake the writing of this first compilation.

This work has been divided into two sections; the first, the chemistry of the furans, in particular the behavior of the furan nucleus and of furfural; the second, the industrial applications of furfural and its derivatives. The first part gives a general account of the chemical preparations and reactions of the furans. For more detailed information, the reader is referred to published works. The second part does not attempt to give a full account of all the industrial applications. Once again the authors have given general uses of furfural and its derivatives, that is, solvent applications, use in the field of resins, and as a chemical intermediate. Bibliographical references are listed for more specific applications. The beginning of this section is devoted to the physiological properties and suggested precautions.

The authors' style is designed for people in industry and research at all levels, in that their ideas and explanations are clearly phrased. The placing of bibliographical references at the foot of the page is a convenience, particularly for the reader seeking information on a specific problem, since so much reference is made to the literature published prior to January 1951.

This book can be used as an encyclopedia for the furan compounds, providing an easy reference for their structure, preparation and behavior. Generalized industrial uses are also given, with many references to specific applications. This book should be of value in the fields of resins, vegetable oils, petroleum, and organic chemistry.

BARBARA GRANT

ELECTRON OPTICS, by O. Klemperer. Second edition, 471 pages, illustrations, 15 × 22 cm. New York, Cambridge University Press, 1953. Price, $9.50.

This monograph summarizes the fundamentals of electron optical phenomena for workers whose interests might cover a wide range of problems in the field. Descriptions of physical systems are included only to amplify mathematical treatments. Hence the book is not intended for readers with only a passing interest in the field. However, for students with a well prepared background and for workers starting out in the field, the book offers a lucid introduction to the subject and serves very well the writer's purpose to provide the qualified reader with a reference book and guide to more specialized literature. There are some four hundred references in the bibliography.

The book begins with a discussion of the mechanics of electrons in motion and geometric optics. From the historical development of variation principles, one is led to the analogy of electron motion in magnetic and electrostatic fields to light wave motion in a medium of characteristic index of refraction. Thus, as with light lenses, we associate with the electron lens the cardinal positions whose determination enables us to compute image position and magnification with respect to a given object. Standard techniques of experimental field plotting and ray tracing are described.

In later chapters, specialized topics of electron lenses and their limitations, emission systems, etc., are then delved into. This constitutes a thorough evaluation of the approximations made in developing the mathematical solutions of the first few chapters.

Only in the final chapter does one encounter "the applications of electron optics in industry and research." Herein are described electron microscopes, synchrotrons, tubes, etc.

This second edition is four times as large as the first edition published in 1939. As one would expect, the second edition was expanded in the "applications" section and in those sections describing the more recent developments in electron optics. ROBERT S. SMITH

THEORETICAL NUCLEAR PHYSICS, by John M. Blatt and Victor F. Weisskopf. 864 pages, diagrams, 16 × 24 cm. New York, John Wiley & Sons, Inc.; London, Chapman & Hall, Ltd.; 1952. Price, $12.50.

Theoretical nuclear physics has experienced very great modifications and revisions during the last fifteen years and has produced, moreover, a huge galaxy of publications of all kinds. In the light of this situation, to keep abreast of everything and know just where he stands is a matter which presents a formidable problem for the physicist who does not have time to read all the literature and yet feels the

desire to view the picture as a whole and even to think critically of its various aspects. For such a person the book by Blatt and Weisskopf comes indeed as a godsend, and the form of presentation in the book is such as to ease the problem of overall understanding to a degree which probably nears the maximum of efficiency in the light of the complexity of the subject.

In cases where the discussions are based on mathematical foundations of complexity, the authors seek, as a rule, to present an outline of the mathematical steps, reserving for special sections or for the Appendix a more complete discussion of mathematical details. The success of such an achievement varies naturally with the degree of preparation of the person who reads the book and, indeed, the authors suggest a one-term course in quantum mechanics as a prerequisite. In this designation of prerequisite it must be admitted that they have adopted a rather high level as a norm for the graduate student who is going to absorb enough quantum mechanics in one semester, when taken in conjunction with his other studies, to form a critical appraisal of all that is in the book. The burden has been considerably lightened by the suggestion of certain sections which may be omitted, and an admirable feature is the incorporation at the end of each chapter of a complete definition of all the symbols used in the chapter. One of the great impediments to reading a book of a highly technical nature, particularly when the reader wishes to concentrate on a certain section thereof, is the impediment created by the necessity of having to read the whole book in order to ascertain what the symbols mean. The authors are to be congratulated on eliminating this obstacle. An analogous element to be commended is that of accompanying the figures by captions sufficiently descriptive of the content of the figures to avoid the necessity of unnecessary reading to understand what they mean.

This reviewer is heartily in favor of the principle of outlining mathematical processes as a whole with sufficient detail to enable the reader to see "how the mathematics works," but with the elimination of details of a more or less purely algebraic nature. However, it must be admitted that in many cases a reasonably complete understanding necessitates that the reader shall, preferably with his own pen or pencil, construct the mathematical details in their entirety or, at any rate, sketch them in their entirety, since the line of demarcation between that which constitutes the analytical details and the working element of the mathematics is by no means always sharp. Perhaps the best economy of effort in this matter is to be found in the reader's segregating off certain fundamental problems which contain in themselves, or in understandable modifications of them, the basic avenues of development in nuclear physics as a whole. Of course, prominent among such problems is the basic one of the scattering of a particle by a nuclear center with a well-defined potential function. In these connections, the Appendix at the end of the book represents a feature of considerable value.

The book comprises fourteen chapters and an appendix in two sections, A and B. The chapters have respectively the titles: General Properties of the Nucleus; Two-Body Problems at Low Energies; Nuclear Forces; Two-Body Problems at High Energies; Three and Four-Body Problems; Nuclear Spectroscopy: I. General Theory; Nuclear Spectroscopy: II. Special Models; Nuclear Reactions: General Theory; Nuclear Reactions: Application of the Theory to Experiments; Formal Theory of Nuclear Reactions; Spontaneous Decay of Nuclei; Interaction of Nuclei with Electromagnetic Radiation; Beta-Decay; Nuclear Shell Structure; while Appendix A deals with angular momentum, operators, and eigenfunctions, and Appendix B, with multipole radiation.

The first chapter is particularly valuable in giving a clear summary of the various nuclear physics concepts which make their appearance later in more detailed forms. The second chapter, while confined to the two-bodied problem for energies below 10 Mev, serves to introduce the essential mathematical mechanisms of that problem and particularly to introduce the concepts of the different kinds of nuclear forces associated with it, including tensor forces. There is also a discussion of the origin of electric and magnetic moments of different order.

In Chapter 3, we meet with the case where many nucleons are involved and with the problem of providing for nuclear stability and saturation conditions. We encounter exchange forces, isotopic spin formulations, etc.

Chapter 4 discusses the two-body problem for higher energies, while Chapter 5 gives a more detailed discussion of three and four-body problems, such as are presented by triton and alpha particles.

Chapter 6 deals in greater detail with the general problem of nuclear stability with special references to the two kinds of stability—that concerned with the splitting of the nucleus into two or more parts, and that concerned with beta-ray emission, etc.

Chapter 7 deals with special nuclear models—the uniform model of Wigner, the independent particle model, the alpha particle model, and the liquid drop model. The discussion of the independent particle model paves the way for its use in Chapter 14. In the discussion of the shell model, the fact that the shell model should be so unexpectedly successful in Chapter 14 in the light of the questionable features associated with its birth in Chapter 7, makes it, perhaps, well that these two chapters should be sufficiently widely separated to provide a breathing space in which one can forget some of the sins confessed in Chapter 7, while enjoying the successes of Chapter 14.

Chapters 8, 9 and 10 deal with the general theory of nuclear reactions, the problem of calculating cross-sections of the various phenomena, etc. Chapter 10 is a more formal theory of the material presented in Chapter 8, and Chapter 9 deals with a comparison with experimental data.

Chapter 11 treats of decay of the nucleus and particularly with alpha-particle decay.

Chapter 12 introduces electromagnetic radiation into the problem of nuclear phenomena. It covers a wide range of related activities—multipole radiation and selection rules—the problem of emission and absorption—radiative transitions in the two-body problem—internal conversion—transitions between low lying states of nuclei—transitions involving highly excited states.

Chapter 13 gives an extensive treatment of beta-decay; and as already stated, Chapter 14 discusses the shell model of the nucleus and it introduces the problem presented by the so-called magic numbers.

As one reads this book, he is impressed with the nascent state of the subject. In the physics of old, we usually had one theory at a time. In the first quarter of the century, we had become accustomed to the situation so aptly described by Sir William Bragg as "Classical Theory on Mondays and Wednesdays, Quantum Theory on Tuesdays and Fridays." In the present state of nuclear physics, we seem to find widely contrasting theories of nuclear models standing up unashamed in one another's presence, each receiving compliments for its successes. The nuclear physicist consults with all of the claimants and is even frequently to be found in the hide-out of old classical electrodynamics himself, seeking from that ancient authority authorizations for what he wants to say or do.

The success of the physicist depends frequently upon his having built up a store of semi-intuitive concepts which he can apply rapidly to gauge the importance of any line of thought which may occur to him. To the experimental physicist, the concepts are in large part concepts of orders of magnitude of effects. To the pure theorist they are in large part concerned with the outcome of certain mathematical forms and processes which are being considered for use towards the desired end of securing certain mathematical properties in the end result. The normal mathematical physicist employs a mixture of these two types of concepts. In the classical era, knowledge and experience were necessary to enable him to judge immediately, and with surety, as to the validity of certain short cuts suggested by the concepts, short cuts whose complete formal justification might involve considerable labor. In classical physics, however, the mental hazards of intuitive argument were those of a territory ultimately consistent in itself as regards the statement of laws necessary to define it. In nuclear physics, however, the underlying background is much more diffuse and the danger involved in intuitive arguments may be much greater. In considering the problem of a deuteron passing by a nucleus, one reads on Page 506:

"The mechanism of the process may be described as follows: Because of the finite size of the deuteron, it may happen that one constituent comes into contact with the nuclear surface before the other one does. Since the nuclear interaction energies are much higher than the binding energy of the deuteron, the nucleon arriving first at the nuclear surface is quickly separated from its partner and forms

a compound nucleus C′. If the second nucleon hits the nuclear surface an instant later, the compound nucleus C(Z + 1, A + 2) is formed just as in. . . ."

One who has come freshly from mental castigation on account of the use of certain arguments founded upon sins against the principle of indetermination and what not, might well fear further castigation if he took comfort in such an argument without very careful scrutiny of its significance. Again, the hankering after classical concepts is illustrated in Footnote 2 on Page 30, where it is even admitted that there is room for surprise in finding an uncharged particle with a magnetic moment. It is even found that comfort may be secured by thinking of the particle as possessing equal and opposite charges, oppositely directed in the rotational motion. These are only two illustrations of the continual desire for the old features of the classical era to supplement the formalism of the new era.

As one peruses this admirable book, one cannot avoid a renewal of disturbance of his philosophic equilibrium in contemplating on one hand (*a*) the apparent extreme naïveté of the concept of particles with forces of various kinds between them, and, on the other hand, (*b*) the extraordinary richness of success which, in spite of all remaining imperfections, has evolved from the naïve concepts. One cannot but wonder after all whether it is not particles, but rather the mathematical forms which particles have dictated which are at the heart of the matter. One may say: "But if the particle reflects the mathematical form, what objection to its presence remains?" The trouble is that the specific concept, such as that of a particle, tends to carry with it certain requirements born of what may be called "the common sense" requirements of the particle. However, the common sense requirements may play no necessary part in the mathematical structure and, indeed, may be a hindrance to it if the particles are allowed to dominate the situation too completely.

Many years ago there was an epoch in which particles of a still more nebulous and ill-defined character tended to dominate the starting points of physics. It was in such an era that the equations of Lagrange were born and had their many successes. Particles with central forces were invoked to eliminate the overall effects of internal forces. As generalization of the mathematical processes to electrodynamics in the hands of Maxwell proceeded, the role of the particle became more and more obscure. The physical picture was too precise to admit of any such particles. Poincaré added some comfort to the situation by showing that starting with any homogeneous quadratic function T of velocities as representative of a kinetic energy, with a potential energy which is a function of the coordinates, it is always possible to assign a system of particles with constant m's for which $T = \frac{1}{2} m(\dot{x}^2 + \dot{y}^2 + \dot{z}^2)$ is this function T, and to assign central forces between the particles and on them from without, such that, when we go through the process of building up Lagrange's equations for these particles, our V will turn out to be the quantity whose derivatives are these external forces; in fact, it is always possible to assign a system of particles controlled by central forces such that the Lagrangian equations which we have are the generalized equations for these particles. Moreover, this can be done in an infinite number of ways.

It is, of course, to be realized that in the electrodynamic problem, these hypothetical particles have nothing whatever to do with electrons and the like. However, the motion of these particles contains implicitly the electrodynamic story. We would obviously land ourselves in a bad mental mess if we tried to do our thinking in terms of these particles instead of in terms of the electromagnetic field itself.

Now in the quantum theory, may it not be that we have a situation like the following but in reverse form? Our intuitions have begun in the particles, whereas they should have begun somewhere else.

In conclusion, the authors are to be congratulated for having produced a book which mirrors in admirable form the status of the subject today, and which, while recognizing the weaknesses of the structure, exhibits the type of thing which has been successful in extracting the maximum of content from that structure.

W. F. G. SWANN

CURRENT TOPICS

Industrial Television Solves a Crime.—Industrial television has solved a case by giving police an eye-witness view of thieves at work. The locale was a stockroom of an RCA television service branch in Hollywood. Inventories had disclosed that television equipment was being stolen on a substantial scale—some $38,000 worth (covered by insurance) was missing on the initial check.

Officials on the spot, recalling the success of RCA industrial television equipment in functioning as an "eye" in locations too dangerous or inconvenient for human observers, decided to try the device as an electronic witness to the crime. Summoning the police, they concealed the camera unit among the rafters of the stockroom with the lens focused on the loading platform. The rest of the unit—the TV receiver and viewing screen—was placed in a second-floor room some distance away.

Every day for two weeks, the TV "eye" was trained on the loading platform as police watched at the receiver. The camera recorded the routine activities at the platform—but it also recorded the suspicious actions of one clerk, who casually placed a number of boxes of TV tubes on the loading platform during the lunch hour on Tuesdays and Thursdays when few other people were around. At apparently pre-arranged intervals, a pick-up truck would back into the driveway, the boxes would be put aboard with the help of the suspect, and the truck would pull away—all before the gaze of the camera and the interested watchers at the TV screen.

Once the facts had been made clear by the TV unit, the trap was set. The police at the receiver waited until the truck took off with another load of tubes. As they moved in to arrest the clerk, a police car trailed the truck to its destination and seized the driver and two alleged confederates.

The hero of the story is an industrial TV unit which already has been put to scores of uses—patrolling, guarding, transmitting fingerprints and signatures, checking numbers of freight cars, supervising operations of machinery at a distance, riding rockets, and generally fitting itself handily into locations where direct view is required and the human eye cannot go.

Its efficiency in these operations, and in its newly-acquired detective role, stems from the compactness of the camera and the fidelity with which it transmits what it sees. The RCA Vidicon tube, heart of the system, is only 6 in. long and an inch in diameter. The camera that is built around the tube is no larger than a 16-mm. movie camera and is easy to handle.

The unit is completed by a connecting cable and a compact control monitor with a ten-inch viewing screen. Other receivers can be attached to the monitor if required, and the controls allow the camera focus to be controlled from the receiving end.

Although TV in this compact form has been available to industry for less than ten years and has been developed by RCA engineers into its present state within the past two years, it has already carved a vital role for itself in a wide variety of jobs. Its recent performance in Hollywood was a new departure, however, and its success as a witness to the crime promises to open a broad field for TV as an electronic arm of the law.

Tiny Tantalum Capacitor.—A tiny tantalum capacitor, believed to be the smallest high capacity unit ever designed for low voltage, direct current applications, has been announced by the General Electric Company's Capacitor Department at Hudson Falls, New York.

It will make possible further size reductions in miniaturized assemblies using transistors and is intended as a companion for the transistor, G–E engineers said.

The new unit is so small—5/16 in. long and ⅛ in. diameter—that it has been termed a "micro-miniature" capacitor. It is the first in a new line of small capacitors being developed by General Electric for miniaturized equipment.

The capacitor can be used in hearing aids and, in many instances, can be applied in transistorized military equipment. G–E engineers believe it will also aid in opening the door for commercial applications of miniature electronic products.

They said the major feature of the unit is the advantage in size per volt microfarad over most other electrolytics. Other features include: long shelf and operating life, wide temperature range, and low leakage current. The unit is sealed against leakage or contamination and utilizes a non-acid electrolyte.

It is designed to operate over a temperature range of −20 C. to +50 C. and is suitable for storage at −65 C.

The new unit is available in ratings from 2 to 16 volts, 4 to 0.7 microfarads, respectively. Another, larger capacitor—½ in. long—with similar characteristics and the same voltage range, but with 8 to 1.5 microfarads, has also been announced as available.

G–E engineers said that, while temperatures below −20 C. will result in further loss of capacitance, the new units continue to be operable and will often give satisfactory values at much lower temperatures. At 10 volts or above and at −55 C., the capacitor will maintain at least 65 per cent of its 25 C. value, according to advance tests. It is also possible to obtain satisfactory performance above 50 C. with some life restrictions, the engineers added.

The units are recommended for non-resonant, non-critical applications such as coupling, by-pass, and filtering, where bulk capacity is useful.

The capacitors have a tantalum anode oxidized to the voltage rating, enclosed in a silver case, and impregnated with non-acid solution. A synthetic plug in the end of the case is roll-crimped into place and a solderable tin-coated nickel lead is lap-welded externally to the projecting tantalum anode lead, permitting connection up to the case. The case itself is the cathode, and is equipped with a tin-coated copper lead soldered to the case. The units are of the polarized type.

Casting Titanium Metal Shapes.—National Research Corporation of Cambridge, Mass., has announced the development of a method for the production of cast shapes of titanium metal. This accomplishment is the result of an intensive program aimed at the development of special vacuum melting furnaces, casting procedures and mold materials capable of withstanding attack by molten titanium. The development was sponsored by National Research Corporation in accordance with Department of Defense policies which encourage private industry to employ its own funds to develop techniques and products to a point where the military can procure material on a purchase order basis.

It is now possible to produce pilot quantities of cast shapes of both pure and alloyed titanium. Castings of complex shape weighing up to several pounds have been made. Carbon, oxygen, and nitrogen content are reasonably comparable with commercial wrought titanium. The surface attainable is equal to that of good sand-cast metals.

National Research Corporation is now under contract to supply pilot titanium castings to the United States Army Ordnance Corps at Watertown Arsenal.

Methods for Faster Map Production.—Negatives are out of style at the Army's Engineer Research and Development Laboratories, Fort Belvoir, Virginia, where topographic engineers are taking a "positive" approach in the field of map reproduction.

Since World War II brought maps down to the common soldier, methods to produce them in great quantities are urgently needed. In an effort to develop a method which will provide photomaps in great numbers for quick delivery to troops in the field, ERDL is investigating the ammonia process which makes prints from a positive film.

The ammonia process, often referred to as the diazotype method, utilizes a paper coated with a light sensitive dye intermediate which can be selectively decomposed or bleached by light. When this paper is exposed to light in contact with a transparent positive original, and after exposure is subjected to ammonia fumes, a direct positive photographic print of the original is produced.

Present methods of ammonia process print production from aerial negatives require that a conventional silver halide film positive be made from the negative. The positive is produced by contact or projection printing using conventional photographic materials, methods and processing. However, the procedure is exacting in that the film positive must be of a specified contrast and density in order to produce satisfactory prints on the continuous-tone ammonia process paper now available.

Once a film positive is available, ammonia process prints are easy to make in a specially designed machine. Only two direct steps, printing and dry development, are necessary. Production of these prints is simple when compared with the making of photographic prints. Five processing steps (darkroom, developing, fixing, washing and drying) are eliminated in the production of large quantities, resulting in great savings in both time and labor.

Continuous studies are being conducted by Army Engineers to improve materials used in the method and to perfect the promising process. Also under development is printing and processing equipment designed for truck mounting and air transport for delivery to topographic units operating in forward area.

New Lab-Type Pulse-Forming Network.—A new universal pulse-forming network, specifically designed for laboratory use in radar research and development, was announced recently by the Sprague Electric Company, North Adams, Mass. The unique construction of this network makes it possible to obtain the five most-needed pulse lengths—$\frac{1}{4}$, $\frac{1}{2}$, 1, 2, and 3 microseconds—with no distortion of the pulse shape.

The flat portion of the pulse form is retained at all pulse lengths through Sprague's method of multiple switching. Common capacitor connections are switched at half network voltage—

an advantage in experimental equipment, and an important factor at higher voltages. All pulse lengths correspond to the half-power point, as measured by the standard synchroscope set-up at 70 per cent voltage level under resistance load. This point corresponds to that at which most radar equipment operates. Also of interest to lab technicians, the rise time remains the same—approximately 0.1 microsecond from the 10 to the 80 per cent level of the curve.

Designated Model H-850, this network is designed for operation with a 50 ohm impedance load. Peak voltage rating is 13 Kilovolts regardless of the pulse length used, which makes the unit useful for normal low power ranges in radar equipment employing hydrogen thyratron tubes.

New Type Penicillin.—Isolation and development of a new type penicillin specially designed to eliminate allergic reactions to the antibiotic drug were described for the first time at the annual meeting of the American Institute of Biological Sciences, held at the University of Wisconsin.

A team of three chemists said the isolation of the new penicillin, known as penicillin O, was the result of a long and painstaking search. The chemists, Drs. Bruce W. Churchill, J. H. Ford and D. R. Colingsworth, of The Upjohn Company, Kalamazoo, Mich., said that sensitivity reactions to standard penicillin, known as penicillin G, have ranged from 1.5 to 10 per cent. These reactions include skin eruptions, abscesses, low-grade fever, serum sickness-like reactions and also, in several cases, death from anaphylactic shock.

Dr. Churchill, who presented the paper, said that one of the most common sensitivity reactions encountered was inflammation of the mouth and tongue caused by the use of penicillin G lozenges or troches. Members of The Upjohn Company research staff known to be sensitive to penicillin G served as guinea pigs, testing new penicillins on their tongues to determine whether they would cause reactions.

First hint of success came with the isolation of a new penicillin, chlorocrotylmercaptomethyl penicillin. "This penicillin," Dr. Churchill declared, "did not cause soreness when it was tested on the tongues of three members of our research staff who had exhibited this reaction with penicillin G."

There was one flaw in the new penicillin, however. Even to chemists, who tend to be innured to pungent and penetrating odors, it had "a disagreeable odor and taste." It was named penicillin S.

The search went on, Dr. Churchill noted, and some time later another penicillin, allylmercaptomethyl penicillin, was isolated. It had a much less objectionable odor and also lacked the tongue-irritating properties of penicillin G. It was named penicillin O. In animal tests the bacteria-killing ability of penicillin O, Dr. Churchill said, was found to be just about equal to that of penicillin G. It proved also to be even less toxic than is G, he added.

"Extensive clinical tests and usage of penicillin O, available under the trade name, Cer-O-Cillin, during the past five years," Dr. Churchill added, "have demonstrated that a very high percentage of patients who were sensitive to penicillin G tolerate penicillin O without allergic manifestations."

The Dying Manikin.—Lifelike manikins are old stuff, but it's a safe bet that the manikin now on exhibit at the U. S. Naval Hospital, Bethesda, Md., is unique. He dies, unless a quick first aider knows how to save him.

Simulating the victim of a major catastrophe, the prostrate "casualty" dribbles blood from his flexible mouth; makes sucking noises through a puncture wound in his chest; bleeds profusely and rhythmically from a severed artery in his arm, has a gaping tear in his abdomen, and a severe gash on his knee. He's gruesome, but with a purpose, since he's as near to the real thing as you can get without blasting somebody, and will help indoctrinate dentists to their roles as emergency physicians in case of atomic attack. An uncanny facsimile of a wounded man, the manikin is constructed of glass-reinforced plastic and equipped with a circulating bloodstream of colored glycerin. And first aid techniques work as well with him as a human being—if you know what to do.

New Airplane Battery Is Ready.—The Navy is getting ready to install the first of some 2000 new, nickel-cadmium aircraft batteries ordered from France, one of which may last the lifetime of an aircraft. Though about three times as expensive as conventional lead-acid batteries, which have a peak endurance of about 100 hours, the new batteries are said to have numerous cost-offsetting advantages. Items: Ninety per cent more ampere-hour capacity, hermetically sealed cells which never need refilling with water; elimination of hydrogen gas during recharging, and a non-corrosive alkaline electrolyte. They can be put anywhere in the airplane where designers can find room since they do not have to be accessible for recharging and charging.

Unscientific Devices Alleged to Prevent Corrosion.—The Inter Society Corrosion Committee has become greatly concerned about the hazards which may result from dependence on certain unproven devices for controlling corrosion and scaling. The Committee recommends that caution be exercised in the application of such devices, since any failure to give protection may result in serious damage to expensive equipment where a real problem of corrosion or scaling exists.

The Inter Society Corrosion Committee is made up of about thirty-five delegates from major technical societies, in the United States and Canada, actively concerned with problems of corrosion control and with the scientific reduction of the economic loss caused by corrosion. By means of this word of caution, and in accordance with its established objectives, the Committee seeks to promote the use of the many scientifically sound and effective devices and processes which are presently available and to discourage dependence on unsound and ineffective methods of control.

The Committee wishes to draw particular notice to devices which are not based on any understandable scientific principle and which are generally promoted on the basis of testimonials from presumably satisfied customers, unsupported by quantitative data. Special attention is drawn to supposedly scientific explanations which make liberal and incoherent use of such terms as catalysis, magnetism, electronics, radiation, etc. Such "explanations" do not appear to have any basis in scientific fact.

In some cases recommendations are made by manufacturers that grounding wires of electrical circuits, if unfavorably connected to pipes in which the devices are installed, should be rearranged or connected elsewhere. The Committee emphasizes that if, because of installation of or after one of these devices has been installed, the electrical circuits are not grounded in

accordance with the National Electrical Code, serious impairment of the safety of persons and property may result.

Against this background, and in line with its responsibilities, the Committee then recommends extreme caution in the application of devices for control of corrosion and scaling that are characterized by supposed operation without any apparent basis of sound scientific principles and for which no adequate engineering performance data are available.

Prevention of Mold Growth in Binoculars.—The use of ionizing radiation from radium and polonium to prevent mold growth in binoculars was reported at the Fall meeting of the Society for Industrial Microbiology, by Sigmund Berk and Leonard Teitell of the Pitman-Dunn Laboratories of Frankford Arsenal, Philadelphia, Pa.

Binoculars were treated with a foil containing radium, a lacquer with radium, and polonium plating. The binoculars containing the radioactive materials were exposed in a chamber which simulated tropical temperatures and relative humidities.

At the end of the exposure, the optical glass of the telescopes treated with polonium was free from mold growth. Polonium emits alpha particles, which are densely ionizing fragments ejected in the disintegration of certain radioactive elements.

The radium foil was effective in preventing mold growth in only half of the telescopes tested. The radium lacquer was ineffective as a fungistat. However, the amount of activity present in the radium samples was less than that in the polonium-treated binoculars.

It was found that the porro prisms were the most difficult optical elements to fungusproof.

The binoculars treated with the radium foil and polonium showed droplet formation on the internal optical glass elements. Also, the metallic parts plated with the polonium were heavily corroded.

It was concluded that ionizing radiation from radium and polonium may be used to prevent mold growth on the optical glass. However, the amounts of these radioactive materials required to completely protect a binocular against fungus growth were considered too hazardous to personnel. Radioactive materials may be used for specialized optical instruments which cannot be fungusproofed by other means.

Corona Detector for High-Voltage Equipment.—A new device for detecting surface corona discharges which often indicate trouble or cause damage to insulation in high-voltage rotating equipment has been announced by the General Electric Company's Special Products Section.

Designed to increase safety factors by having all cable shields, metal fittings, and case at ground potentials, the portable electronic equipment is for manufacturers of large electrical apparatus such as turbine-generators and high-voltage motors. It was developed by the company's General Engineering Laboratory.

The corona detector consists of a probe mounted at the end of a 10-ft, insulating pole, a control box, and necessary connecting cables. In operation the control box is connected to a standard oscilloscope (not part of the equipment) which gives a visual indication of the corona.

The probe is a small capacitor covered with a plastic compound. When it is placed near a corona source, the variations in charge result in corresponding variations in the voltage on

the probe electrodes. These variations are applied to a resonant circuit and cause it to oscillate momentarily. The pulse-type oscillations are then amplified and appear on the oscilloscope screen as a corona indication.

In operation the unit under test is ordinarily submitted to a normal test voltage (line-to-ground value in most cases). The probe is positioned on a bar and pushed firmly in place, the peak-to-peak value of the corona is recorded from the oscilloscope screen, and comparative readings are made on all bars.

Operating power is furnished by a 67½-volt dry cell battery and a 1½-volt dry cell filament battery. Resonant frequency of the unit is 10 kc.

Laboratory Dishwasher.—Many scientists who now spend much of their valuable time washing test tubes, flasks, and beakers will soon be freed of this tedious and time-wasting task according to an announcement by the Chemical Rubber Company, Cleveland that they will introduce a fully automatic dishwasher adapted especially for laboratory use.

B. J. Starkoff, vice-president and general manager of the company, said the new device—called the CRC Labwasher—is designed primarily for use in laboratories to free highly paid and highly skilled scientists from a task that can be easily done by a low-cost machine.

"The Labwasher is manufactured for us by the Electric Appliance Division of the Westinghouse Electric Corporation, Mansfield, Ohio," Mr. Starkoff said. "To adapt it for laboratory use, Chemical Rubber Company has developed special racks which accommodate over 90 percent of the most-used laboratory glassware."

Believed to be the first automatic dishwasher adapted especially for laboratory use, the CRC Labwasher will have the same operating cycle and general outside appearance as today's Westinghouse electric dishwashers for home use. With the advantages of front opening and top loading, the Westinghouse dishwasher was chosen as being ideally suited for laboratory use as counter top space is limited in most laboratories.

The washing action of the CRC Labwasher is also especially suited for laboratory use since nothing moves inside the washer but the water once it starts operating. The glassware remains stationary in the racks while an impeller swirls the water upward at an angle to assure efficient distribution of water inside and over every piece in the Labwasher. With this type of washing action, the thin-walled glassware is handled more gently than it would be if washed by hand—and by eliminating a large amount of glass breakage, the Labwasher is expected to reduce laboratory operating costs.

The CRC Labwasher has been designed primarily for the industrial laboratory. It effectively washes and dries glassware containing either oil or water soluble material. It will accommodate almost all types of flasks up to two or three liter size, as well as beakers, funnels, cylinders, graduates, and many other shapes and forms.

It is estimated that there are approximately 40,000 commercial laboratories in the United States developing new products and improving old products for industrial concerns. With this number, in addition to the countless laboratories in educational institutions and medical research centers, Mr. Starkoff estimates the Chemical Rubber Company's Labwasher will contribute this year toward the saving of literally thousands of valuable man-hours by freeing scientists from the chore of washing glassware.

Consulting Engineers

HARRIS-DECHANT ASSOCIATES
Fidelity-Philadelphia Trust Building
Philadelphia, Pa.

FREDERIC R. HARRIS, INC.
27 William Street New York, N.Y.

Consulting Engineers
Naval Architects

EGGLY-FURLOW ENGINEERS
Consulting Engineers
PHILADELPHIA 2, PA.
1500 Walnut Street
Telephone: PEnnypacker 5-1197

DAMON & FOSTER
Consulting Engineers
Surveyors
CHESTER PIKE & HIGH ST.
SHARON HILL, PA.

CHARLES S. LEOPOLD
Consulting Engineer
◆
213 SOUTH BROAD ST.
PHILA. 2, PA.

P. L. DAVIDSON
Consulting Engineer
◆
Philadelphia, Pa. and
Greensboro, N. C.

W. B. COLEMAN & CO.
Metallurgists - Chemists - Engineers
Spectrographic and Spectrophotometric Analysis
Chemical and Physical Testing—Microscopic Investigation
Huey and Salt Spray Corrosion Tests—Boiler Water Conditioning
9TH & RISING SUN AVE., PHILADELPHIA 40, PA.

A COMPLETE PRINTING SERVICE

GOOD PRINTING does not just happen; it is the result of careful planning. The knowledge of our craftsmen, who for many years have been handling details of composition, printing and binding, is at your disposal. For seventy-five years we have been printers of scientific and technical journals, books, theses, dissertations and works in foreign languages. Consult us about your next job.

. PRINTERS OF . JOURNAL OF THE FRANKLIN INSTITUTE

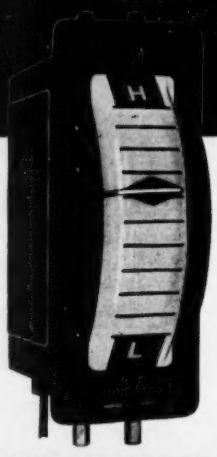
LANCASTER PRESS, Inc.

PRINTERS • BINDERS • ELECTROTYPERS

ESTABLISHED 1877 LANCASTER, PA.

YARWAY

REMOTE LIQUID LEVEL INDICATOR



Now . . . a more accurate check on hard-to-see overhead boiler water gages . . . right in front of your eyes on the instrument panel or other convenient place.

Operated by the boiler water itself . . . by the pressure differential between a constant head of water and the varying head of water in the boiler drum.

Indicating mechanism is never under pressure, due to unique magnetic transmission from pressure side to indicating side of instrument. Action is instant, constant, frictionless. There are *no stuffing boxes.* Mechanism is perfectly balanced on jewelled bearings outside of the pressure chamber. Suitable for all pressures up to 1500 psi. Bulletin WG-1823.

YARNALL-WARING COMPANY

132 Mermaid Ave., Philadelphia 18, Pa.

BIDDLE
Instruments

and miscellaneous laboratory equipment cover a wide field of electrical, mechanical and scientific testing, measuring and experimental work.

For a complete file of all our products write for Bulletin 19-53

JAMES G. BIDDLE CO.
Electrical & Scientific Instruments
1316 Arch Street—Philadelphia 7, Pa.

The Franklin Institute, a privately endowed institution which exists today only because of the generous benefactions of its supporters, is justly proud of the dividends in human benefits accrued from the investments made through the years by its friends. The accumulation of many bequests for general endowment and income to be used where it will do the most good, is the most important and pressing need of The Franklin Institute today.

Checks should be made payable to The Franklin Institute and sent to The Franklin Institute, 20th and The Parkway, Philadelphia 3, Pennsylvania.

Transfer of property should be made to The Franklin Institute.

A typical form is:

I hereby give and bequeath to The Franklin Institute of the State of Pennsylvania the sum of.....to be used as The Board of Managers of The Franklin Institute may think advisable for the benefit of said Institution. (For the principal and income thereof to be devoted to.....).

Additional information on gift and memorial opportunities may be obtained through the above address.

Almo RADIO COMPANY
Executive Offices & Warehouse
412-16 N. SIXTH STREET • PHILADELPHIA 23 • PA.
Corner Sixth & Willow

6 LOCATIONS TO SERVE YOU

WILMINGTON, DEL.
Cor. 6th & Orange
Wilmington 5-5161

509 ARCH STREET
PHILA. 6, PA.
WAlnut 2-5153

6205 MARKET STREET
PHILA. 39, PA.
ALlegheny 4-1706

ATLANTIC CITY, N. J.
4401 VENTNOR AVE.
Atlantic City 2-5928

CAMDEN, N. J.
1133 HADDON AVE.
EMerson 5-1960

ARTHUR H. THOMAS COMPANY
LABORATORY APPARATUS and REAGENTS
Selected for Chemistry and Biology
15,000 Apparatus Items and 6,000 Reagent Items carried in our Warehouse stock for immediate shipment
WEST WASHINGTON SQUARE PHILADELPHIA 5, PA.

PRECISION RULINGS ON GLASS
Scales • Grids • Reticles
Halftone Screens
MAX LEVY & CO. • Wayne Ave. & Berkley St. Phila., Pa.

Your Electronic Requirements . . .
can best be served by RESCO'S Industrial Dep't. Trained and efficient personnel, plus parts and equipment from all of the finest manufacturers in the country, offer you the service and dependability necessary to meet the exacting needs of the industrial plant or laboratory.
Radio Electric SERVICE CO. OF PENNA., INC.
Main Store and Executive Offices
7th and Arch Streets, Phila. 6, Pa.
LO 3-5840 Free Parking
BRANCH STORES
3412 Germantown Ave. • 6930 Market St.
Allentown • Wilmington • Easton

Commercial Stationery
Loose Leaf—Blank Books
Filing Equipment
Office Supplies

SHANAHAN & CO.

22 S. 18 St. Ri 6-0333

WHERE QUALITY OF REPRODUCTION IS ESSENTIAL...
BUT ECONOMY IS IMPORTANT...

The answer is Atlas
Photo Engraving Co
1208 Cherry Street Philadelphia, Pennsylvania

BOLGER-PARKER COMPANY
Hauling and Rigging Contractors
752 N. MARKOE ST.
RESIDENCE PHONES
BOULEVARD 3295
SUNSET 9397M
PHILADELPHIA 39 PA.

Franklin Institute Books are bound by

FEHR & JOHNSON, INC.

Fine Bookbinding

831 Cherry Street
Philadelphia 7, Pa.

HEADQUARTERS
FOR
RADIO PARTS ELECTRONIC COMPONENTS
GEIGER-MÜLLER COUNTER TUBES
AND
RADIO ACTIVITY DETECTORS

HERBACH & RADEMAN
1204 ARCH STREET PHILADELPHIA 7, PA.

KEARNEY LUMBER COMPANY

Lumber of every description for every purpose

2916–26 Kensington Ave.
GA 6-5720 Phila., Pa.
"Our Fleet of Trucks Deliver Anywhere"

Everything in Paints and Paint Supplies . . . .

BUTEN'S
PAINT STORES

Philadelphia Chester Reading Camden
Upper Darby Bryn Mawr

AWARDS BY THE INSTITUTE

The Franklin Medal (1914—Gold Medal).—This medal is awarded annually to those workers in physical science or technology, without regard to country, whose efforts, in the opinion of the Institute, acting through its Committee on Science and the Arts, have done most to advance a knowledge of physical science or its applications.

The Elliott Cresson Medal (1848—Gold Medal).—This medal is awarded for discovery or original research, adding to the sum of human knowledge, irrespective of commercial value; leading and practical utilizations of discovery; and invention, methods or products embodying substantial elements of leadership in their respective classes, or unusual skill or perfection in workmanship.

The Howard N. Potts Medal (1906—Gold Medal).—This medal is awarded for distinguished work in science or the arts; important development of previous basic discoveries; inventions or products of superior excellence or utilizing important principles.

The John Price Wetherill Medal (1925—Silver Medal).—This medal is awarded for discovery or invention in the physical sciences or for new and important combinations of principles or methods already known.

The Edward Longstreth Medal (1890—Silver Medal).—This medal is awarded for inventions of high order and for particularly meritorious improvements and developments in machines and mechanical processes. In the event of an accumulation of the fund for medals beyond the sum of one hundred dollars, it is competent for the Committee on Science and the Arts to offer from such surplus a money premium for some special work on any mechanical or scientific subject that is considered of sufficient importance.

The Louis E. Levy Medal (1923—Gold Medal).—This medal is awarded to the author of a paper of especial merit, published in the JOURNAL OF THE FRANKLIN INSTITUTE, preference being given to one describing the author's experimental and theoretical researches in a subject of fundamental importance.

The George R. Henderson Medal (1924—Gold Medal).—This medal is awarded for meritorious inventions or discoveries in the field of Railway Engineering.

The Walton Clark Medal (1926—Gold Medal).—This medal is awarded to the "author of the most notable advance in knowledge or improvement in apparatus, or in method concerning the science or the art of gas manufacture or distribution or utilization in the production of illumination, or of heat, or of power."

The Frank P. Brown Medal (1938—Silver Medal).—This medal is awarded to inventors for discoveries and inventions involving meritorious improvements in the building and allied industries.

The Newcomen Medal (1943—Gold Medal).—This medal is awarded, not oftener than once in three years, for achievement in the field of Steam.

The Francis J. Clamer Medal (1943—Silver Medal).—This medal is awarded at least once in five years for meritorious achievement in the field of Metallurgy.

The Stuart Ballantine Medal (1946—Gold Medal).—This medal is to be awarded in recognition of outstanding achievement in the fields of Communication and Reconnaissance which employ electromagnetic radiation.

The Boyden Premium (1859).—This premium is awarded not oftener than once in five years to any resident of North America who has recently made a notable experimental determination of the speed, in free space, of radiation in any region of the entire spectrum.

The William M. Vermilye Medal (1937—Bronze Medal).—This medal is awarded not oftener than biennially in recognition of outstanding contribution in the field of Industrial Management.

The Certificate of Merit (1882).—A Certificate of Merit is awarded to persons adjudged worthy thereof for meritorious inventions, discoveries or improvements in physical processes or devices.

For further information relating to these awards apply to The Executive Vice-President

(Revised to May, 1953.)

THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA

welcomes as members all those interested in its purposes and its activities

ANNUAL MEMBERS

Sustaining	$50.00
Active Family	20.00
Active	15.00
Active Non-Resident (50 miles or more from Philadelphia)	7.50
Associate Family	10.00
Associate	5.00
Student (under 25), with Library privileges	3.00
Student (under 25), without Library privileges	2.00

LIFE MEMBERS

Active	$300.00
Active Non-Resident (50 miles or more from Philadelphia)	100.00
Associate	100.00

PRIVILEGES

Free admission to the Museum, Planetarium, and Institute Lectures is granted to all members and to the families of Sustaining, Active Family, and Associate Family members.

The Institute News, which includes news items about the Institute as well as announcements of meetings and lectures, is sent to all members.

The *Journal of The Franklin Institute* is sent to Sustaining, Active Life, Active Family, and Active members.

Use of the Library is granted to Sustaining, Active Family, Active, and Active Non-Resident, as well as to the $3.00 Student members.

THE FRANKLIN INSTITUTE **Benjamin Franklin Parkway, Philadelphia 3, Pa.**

Gentlemen: I desire to contribute to the work of The Franklin Institute by enrolling as _____ Member, for which I enclose payment of $_____ the amount due per annum.

NAME _____
(Please print)

ADDRESS _____

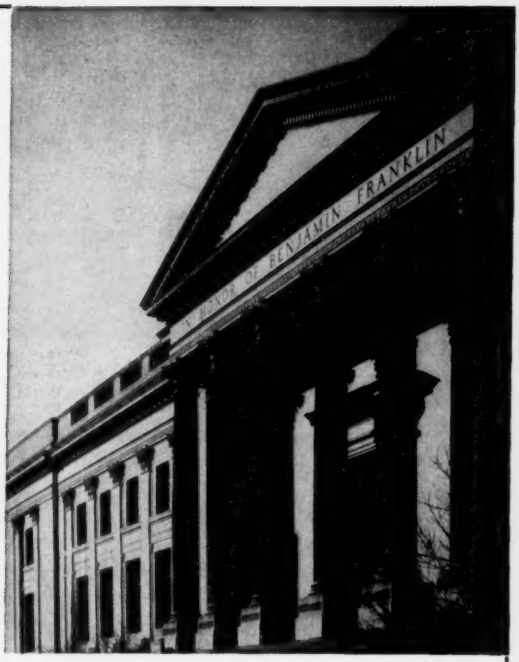
_____

_____

SIGNATURE _____

Membership contributions are deductible for income tax purposes.

The Franklin Institute Laboratories for Research and Development



One of the nation's largest industrial research laboratories

Where a fully qualified staff of engineers and scientists works as a competent and versatile research team—bringing a fresh scientific approach to problems of materials, methods and machines of modern industry.

in the fields of

Chemistry and Physics • **Electrical Engineering**
Mechanical Engineering • **Solid State Physics**

THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA

BENJAMIN FRANKLIN PARKWAY AT 20TH **PHILADELPHIA 3, PA.**